Prototype-3 EMCal shower calibration

Jin Huang (BNL)

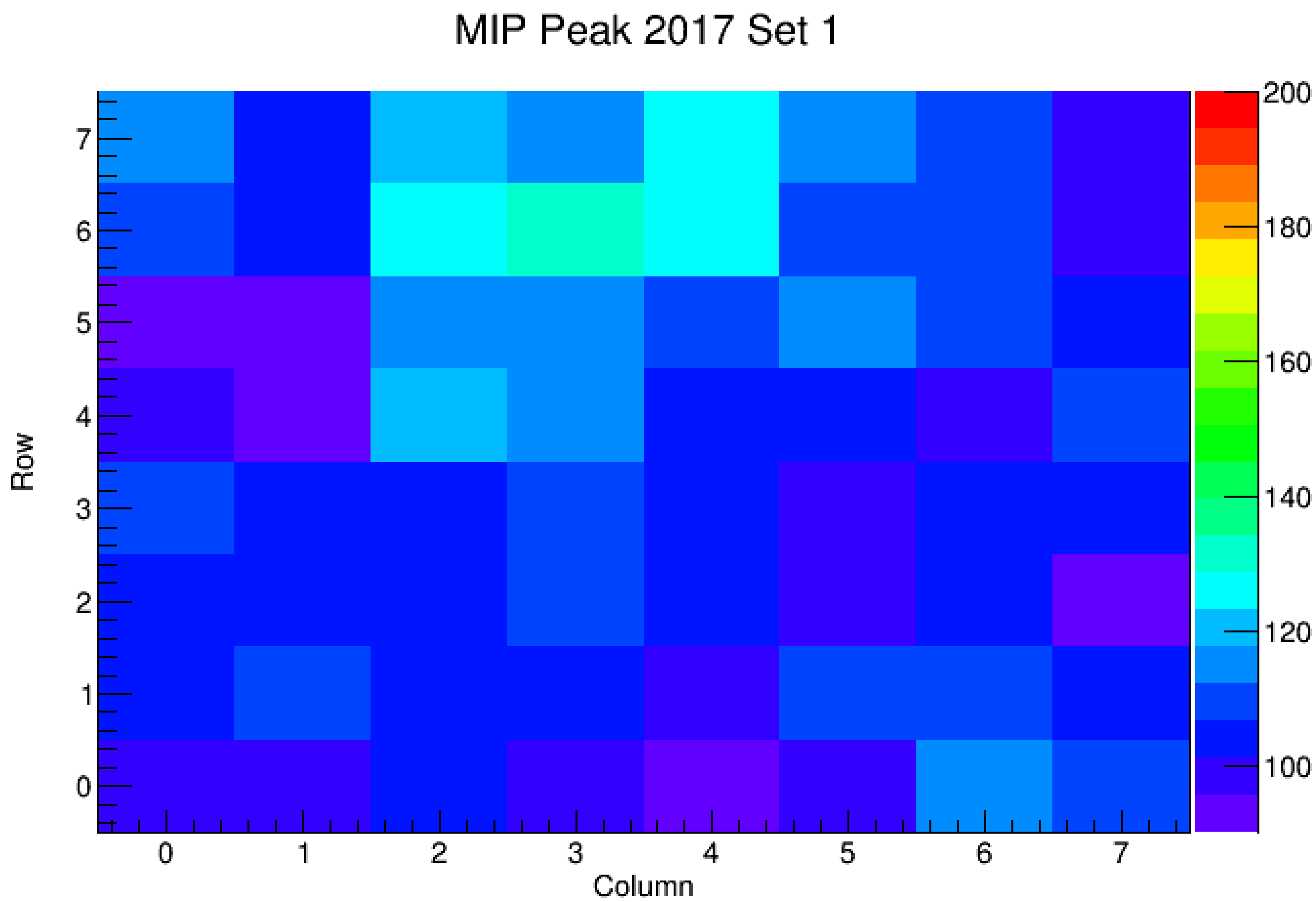
PHENIX

Shower calibration:

- Use 3x3 cluster to balance gain on EMCal by minimizing cluster energy peak around beam energy, 6x6 free parameter (tower-by-tower gain adjustment)
- Related topics:
  - MIP calibration by Mike Skoby from last meeting
  - Data set: Position scan by Zhaozhong Shi from this meeting

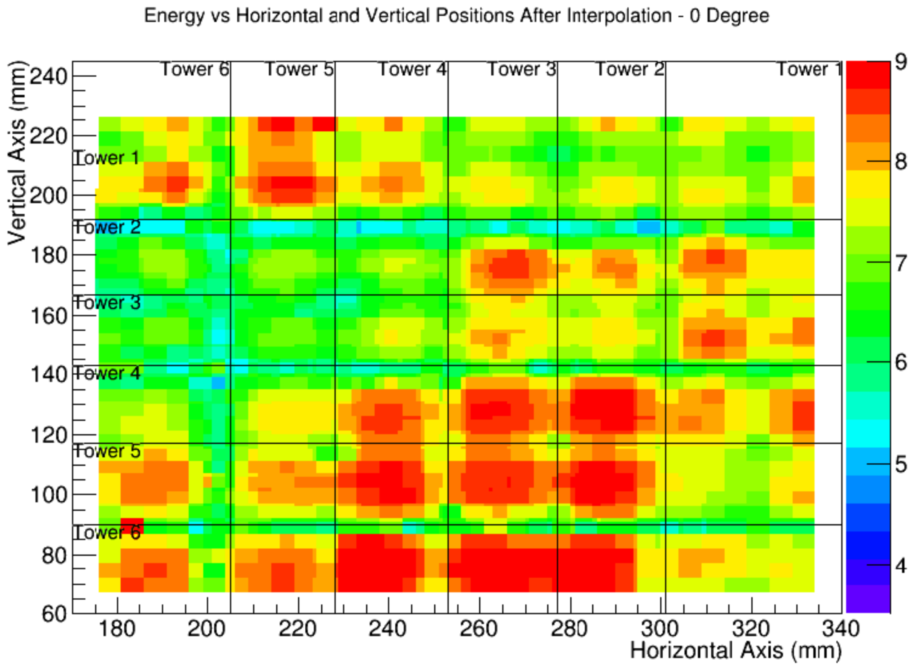
Basline MIP scan data - Mike Skoby

https://wiki.bnl.gov/sPHENIX/index.php/2017_calorimeter_beam_test/EMCal_runs_and_analysis#Prototype3_EMCal_MIP_scans



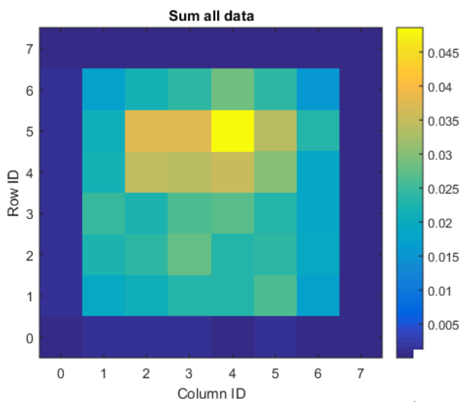
But not balancing out gain based on position scan data - Zhaozhong Shi

- Wiki page: https://wiki.bnl.gov/sPHENIX/index.php/2017_calorimeter_beam_test/EMCal_runs_and_analysis#EMCAL3_third_position_scan_.280_degree.29
- 8 GeV beam scan over 6x6 central tower
- Addition to MIP calibration, position scan based on 8-GeV shower is additionally sensitive to variation of shower sampling fraction or inverse of module density

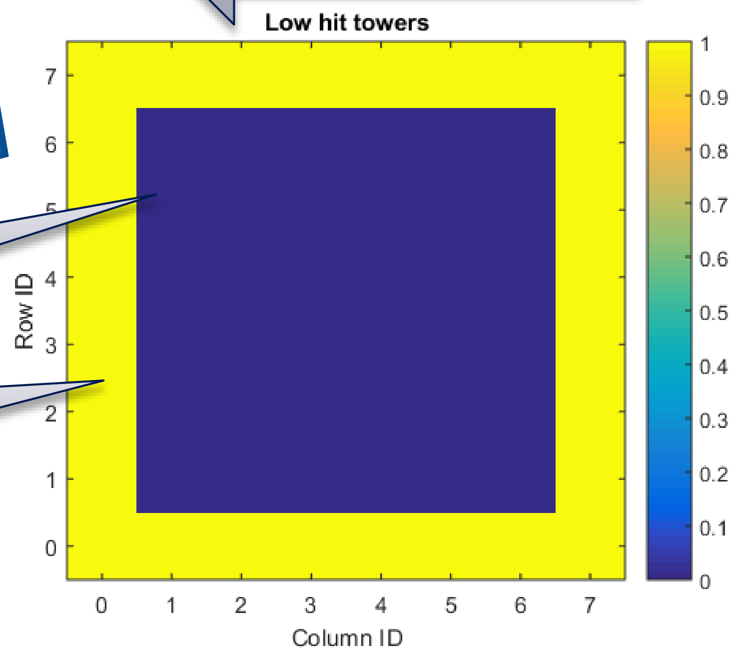


Check data coverage: significant improvement in 2017 prototype

2017 data on prototype3



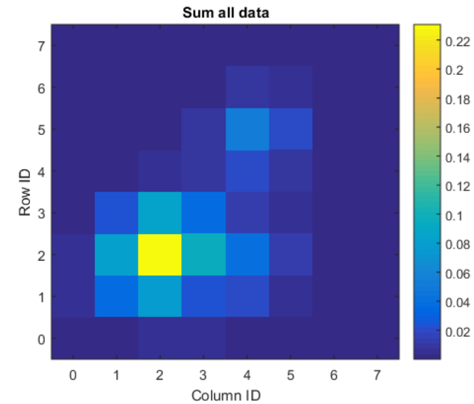
Cumulated event*energy in each tower.
Selection: shower near tower center

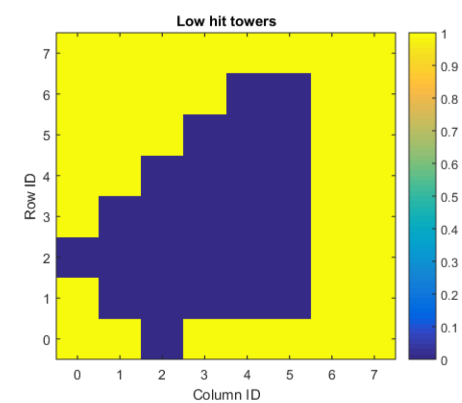


Tower has calibration

Tower has too few data

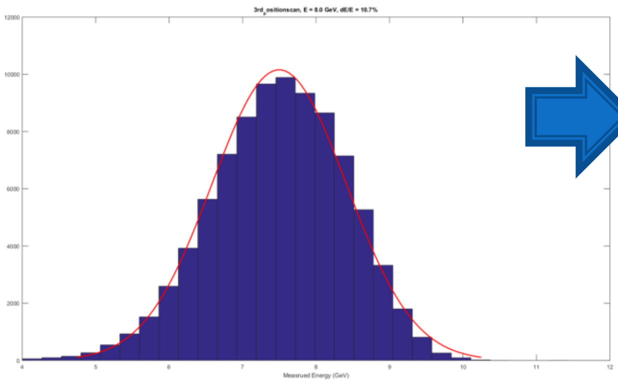
2016 data on prototype2



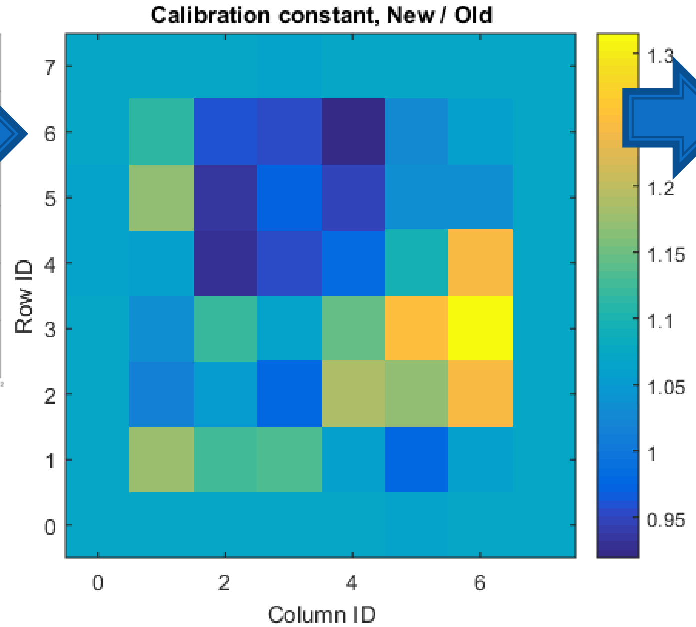


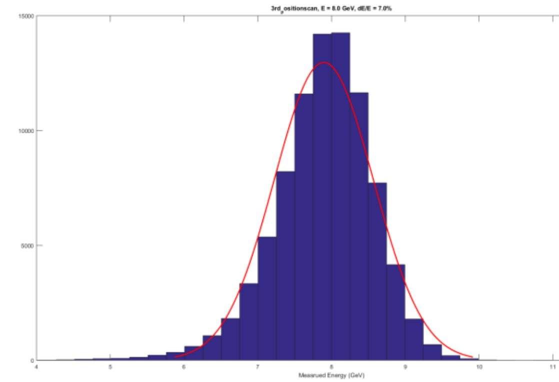
Shower calibration

- Use 3x3 cluster to balance gain on EMCal by minimizing cluster energy peak around beam energy, 6x6 free parameter (tower-by-tower gain adjustment)



Cluster energy (GeV)

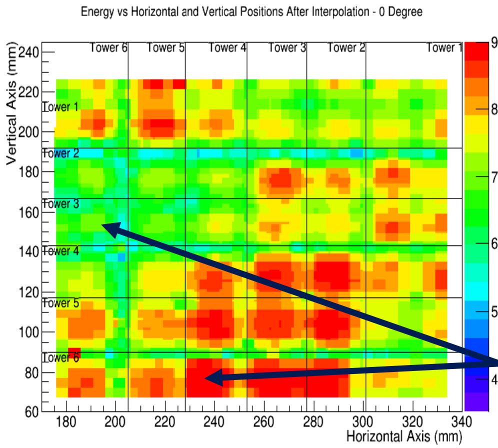


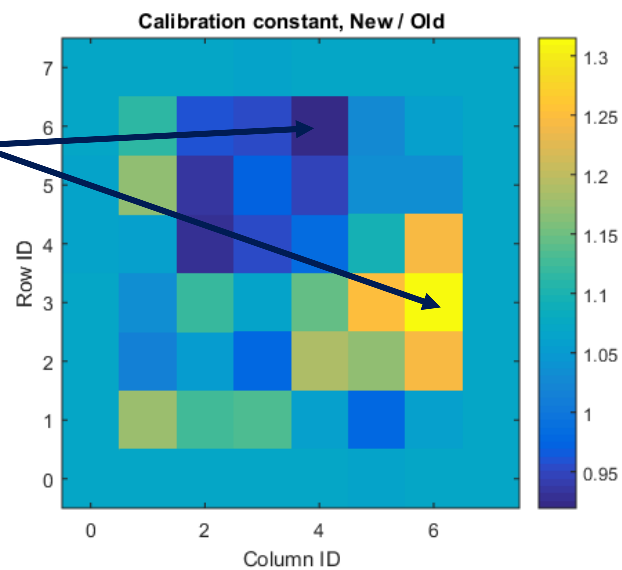


Cluster energy (GeV)

Comparing to position scan – Zhaozhong Shi

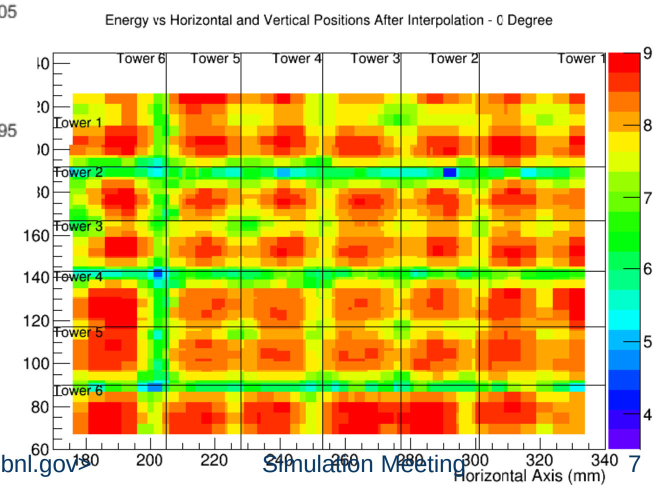
MIP calibration





Note: the axis sign is reversed from position to col/row IDs

Shower calibration

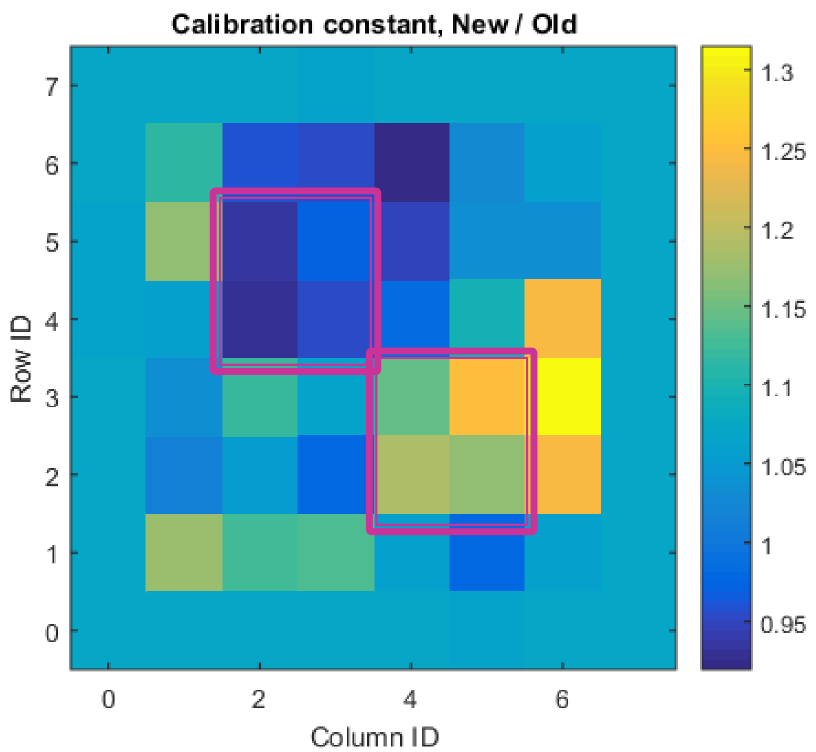


Comparing to density data

Addition to MIP calibration, shower energy calibration is additionally sensitive to variation of shower sampling fraction or inverse of module density

2x2 block density measurement (g/cm^3)
From Sean Stoll
(Assuming front view orientation?)

19-1	20-4	21-2R	22-4R
10.07	9.74	10.08	9.92
19-2	20-3R	21-1	22-2
10.00	10.09	9.83	9.73
19-4	20-1	21-3	22-3
9.85	9.74	9.61	9.80
19-3	20-2	21-4	22-1
9.92	9.63	9.78	9.78



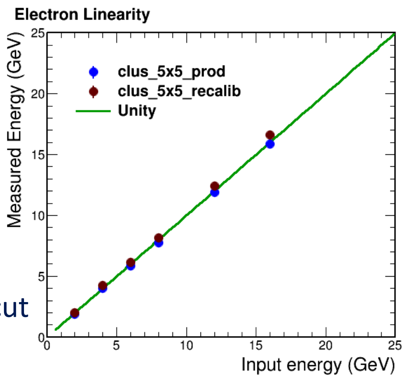
Test in energy scan data with shower-based recalibration

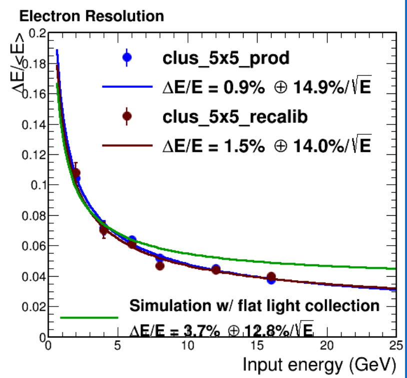
- Wiki: https://wiki.bnl.gov/sPHENIX/index.php/2017_calorimeter_beam_test/EMCal_runs_and_analysis#Analysis_of_Second_EMCAL3_energy_scan

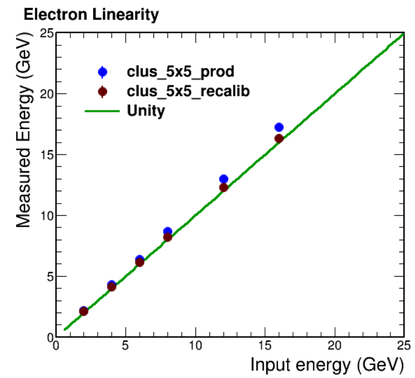
Tower 21

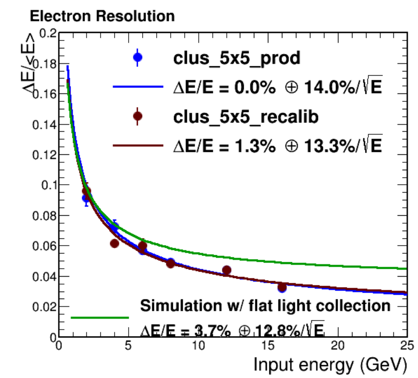
Tower 45

1x1 central hodoscope cut

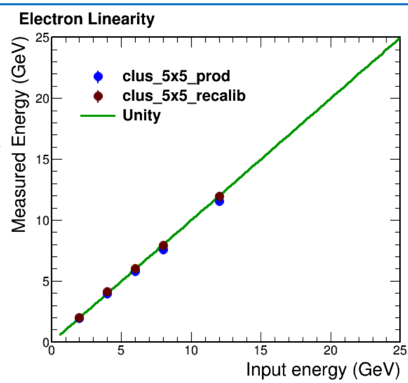


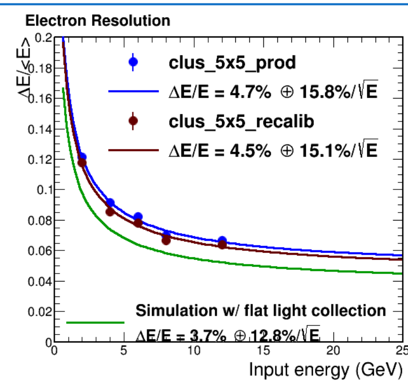


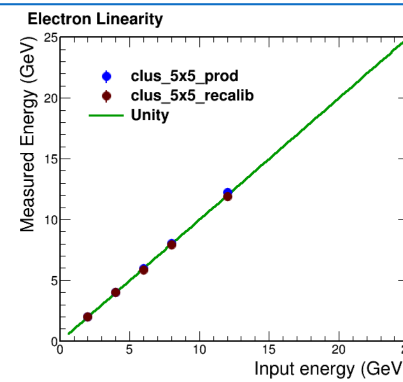


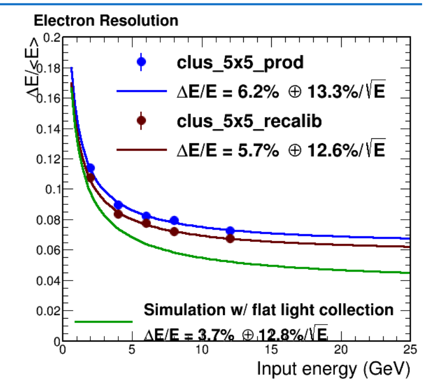


5x5-hodoscope cut towards block center









Summary

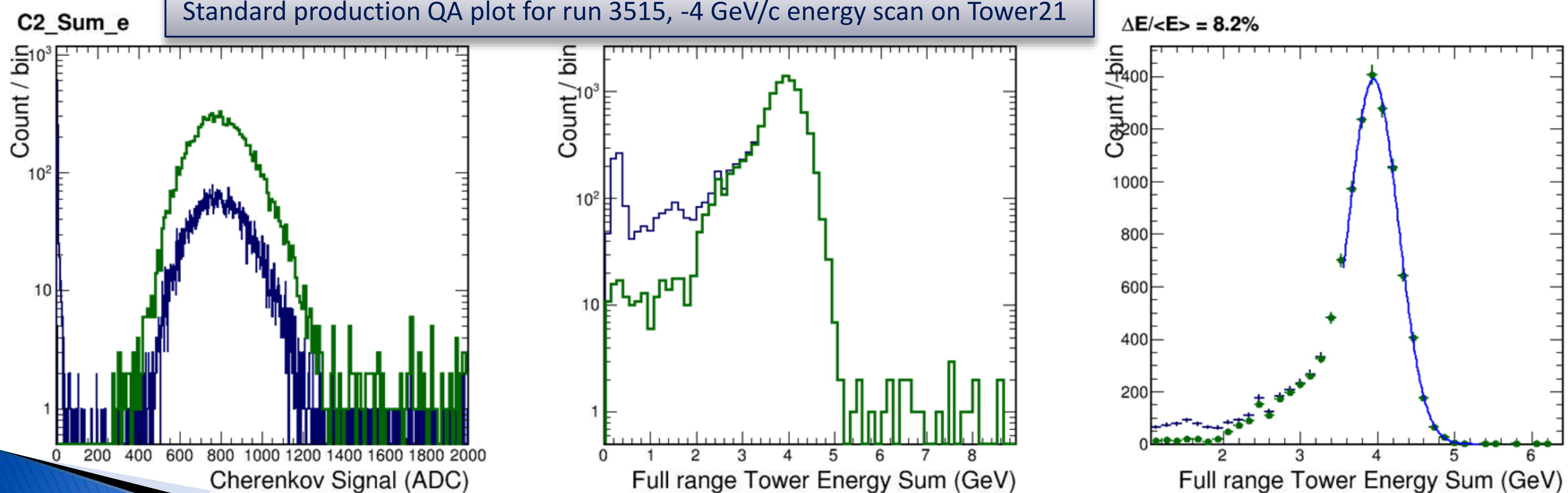
- Much easier data set to handle shower calibration with 6x6-tower position scan
- Good correlation with position scan response
- Need to double check block density correlation
- Improves energy resolution with larger-area hodoscope cuts
- Has calibration constant, ready for a new production

Extra information

Second energy scan started last night

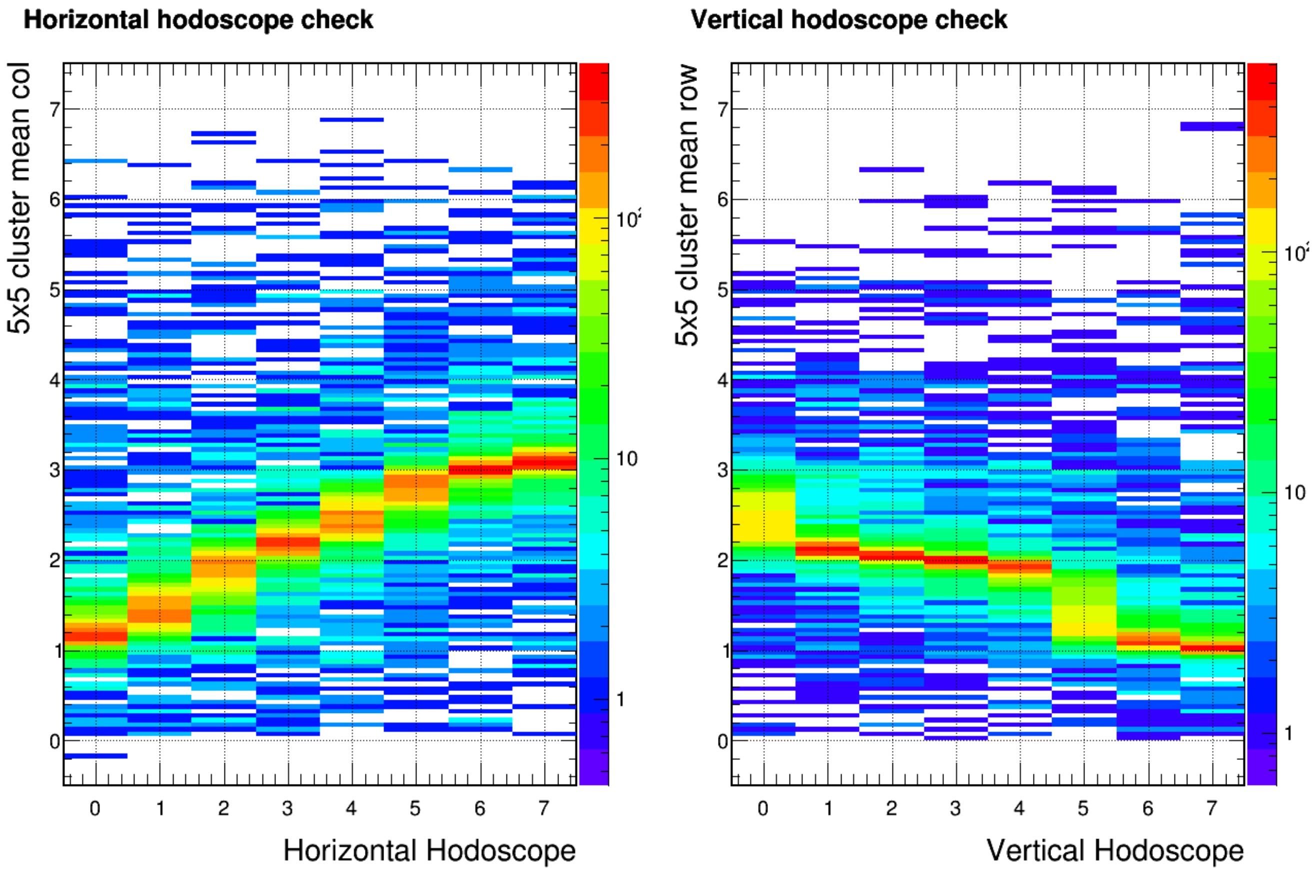
- Improvement over 1st-energy scan (not-analyzable)
  - Fix EMCal "gain" problem
  - Amplified Cherenkov signal so in similar range as last run
  - 3-energy point taken on tower 21 so far before beam problem
- Private test production with Mike's MIP calibration:
  /gpfs/mnt/gpfs02/sphenix/sim/sim01/phnxreco/users/jinhuang/sPHENIX_work/Prototype_2017/Production_0130_WithEMCalCalib
- Once MIP calibration finalize with simulation correction, plan to release official production and tutorial to the list
- Analysis code for this talk:
  - Analysis module: https://github.com/sPHENIX-Collaboration/analysis/tree/master/Prototype3/EMCal/ShowerCalib
  - Plotting macro: https://github.com/sPHENIX-Collaboration/analysis/blob/master/Prototype3/EMCal/macros/DrawPrototype3ShowerCalib.C

Standard production QA plot for run 3515, -4 GeV/c energy scan on Tower21



beam_00003515-0000_DSTReader.root_DrawPrototype3EMCalTower_EMCDistribution_SUM_Energy_Sum_CEMC_C2_Sum_e_Valid_HODO_Trigger_VETO.png

Hodo scope checks – nice correlation



Run 3514-3516, -2 to -6 GeV/c energy scan on Tower21

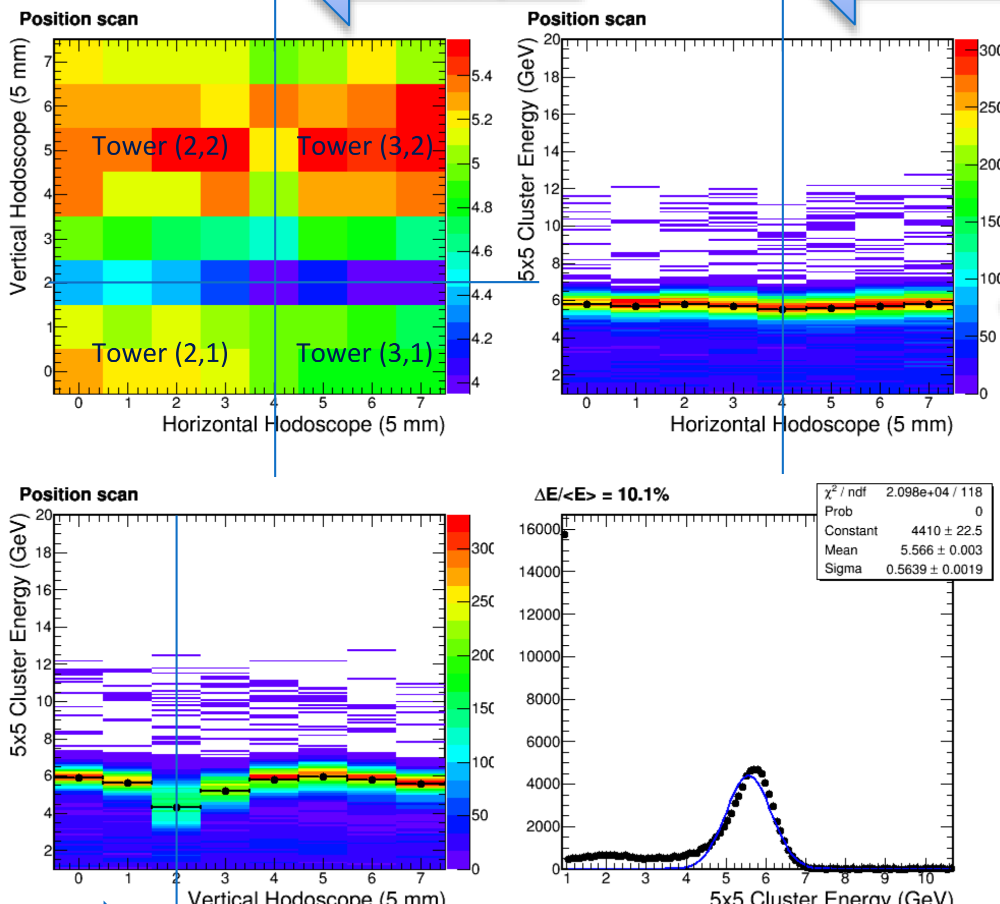
Position dependent energy response check

Light-guide boundary

Light-guide boundary

Block boundary

~10% variation



Cuts:

- MIP calibration
- 5x5 cluster energy with max energy response
- C2 Cherenkov sum>500
- Veto counters<15
- Single horizontal and vertical horoscope finger>30

Block boundary,~30% variation

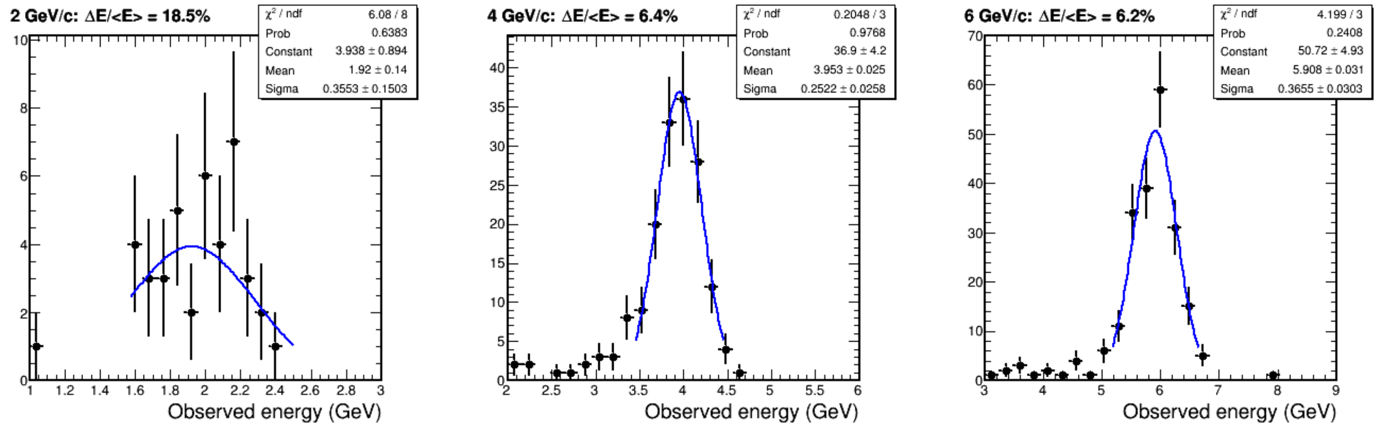
Run 3514, -6 GeV/c energy scan on Tower21, cut on electrons

Electron line-shape for tower 21

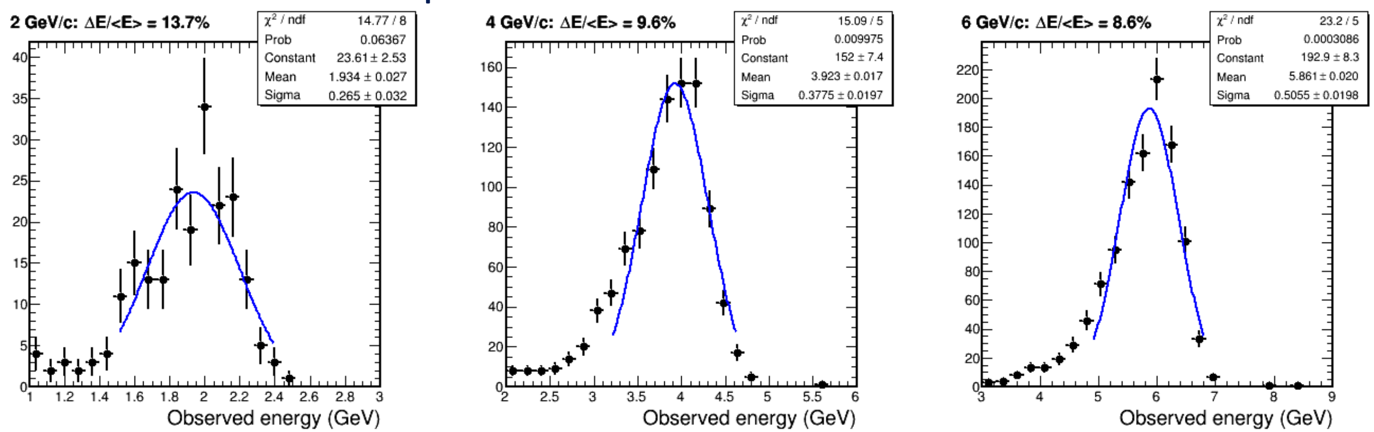
Cuts:

- MIP calibration
- 5x5 cluster energy with max energy response
- C2 Cherenkov sum>500
- Veto counters<15
- Single horizontal and vertical horoscope finger>30

Center 1x1 hodoscope cut @ (h=3, v=3)



Center 2x3 hodoscope cut



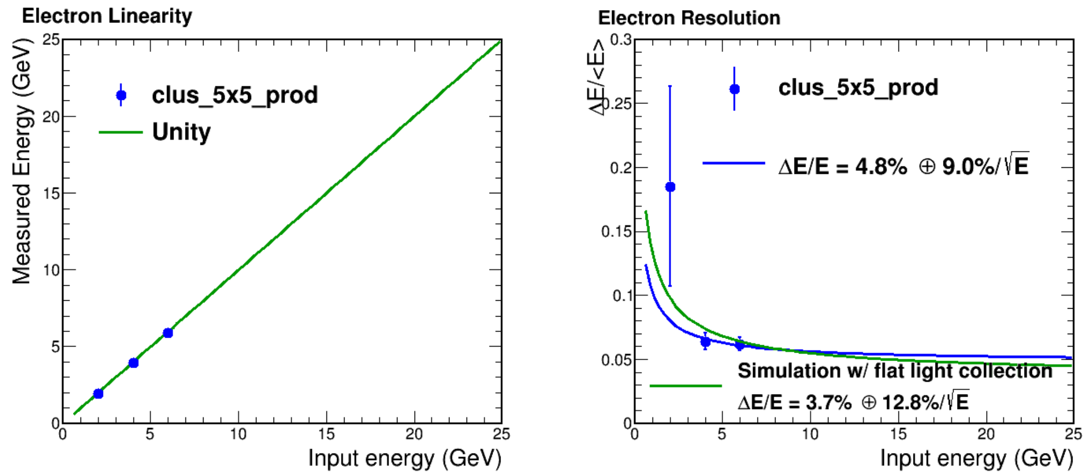
Resolution check so far for tower 21

Cuts:

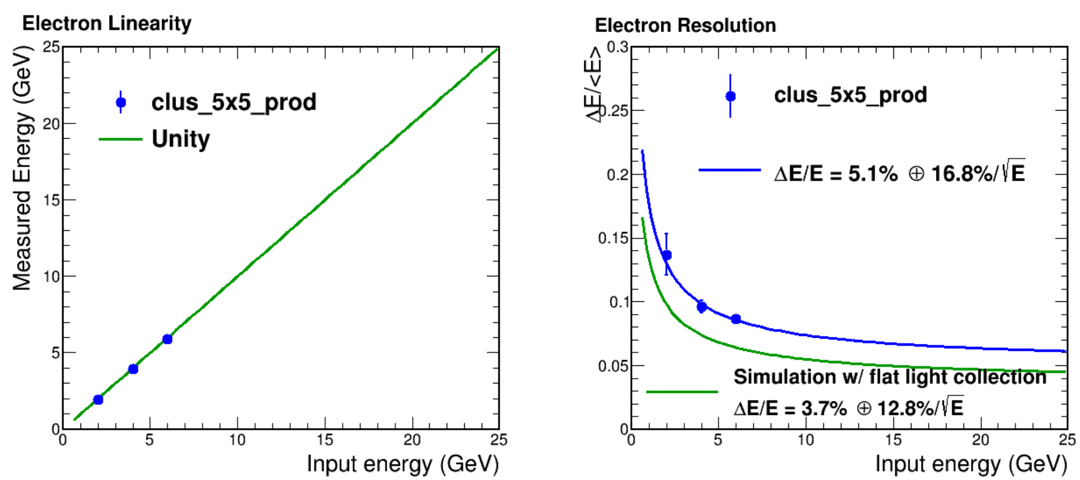
- MIP calibration
- 5x5 cluster energy with max energy response
- C2 Cherenkov sum>500
- Veto counters<15
- Single horizontal and vertical horoscope finger>30

- So far center tower response consistent with simulation with flat light response
- Observe effects of position dependence when using 2x3 hodoscopes

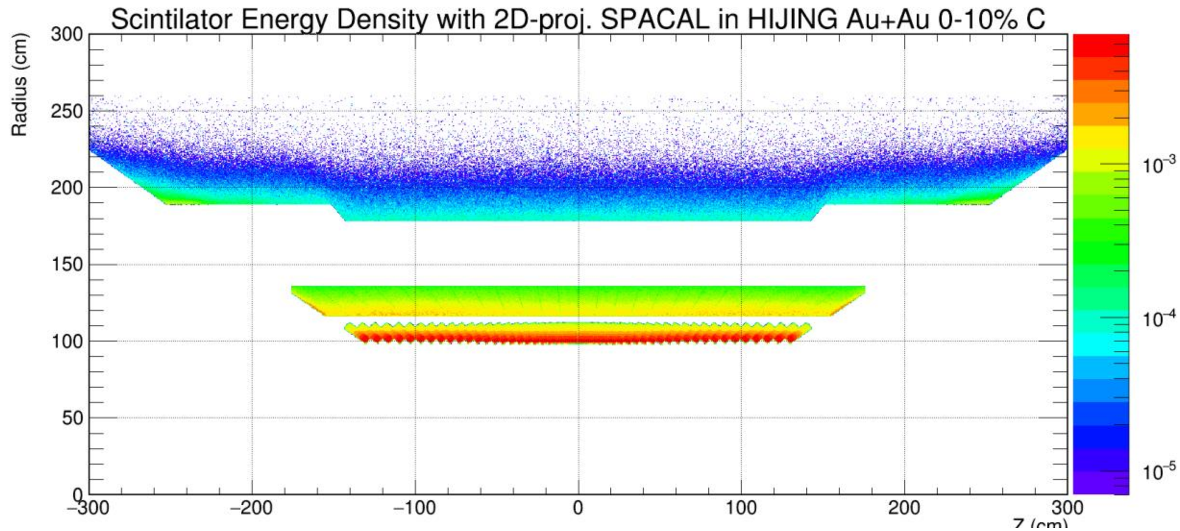
Center 1x1 hodoscope cut @ (h=3, v=3)

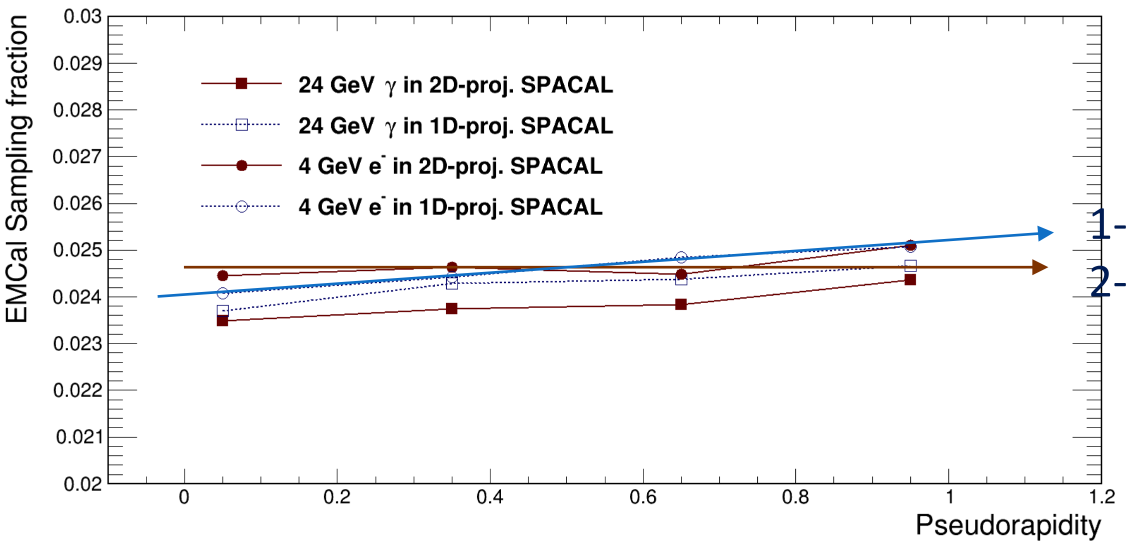


Center 2x3 hodoscope cut



Expectation from sPHENIX pre-CDR simulations: Sampling fraction



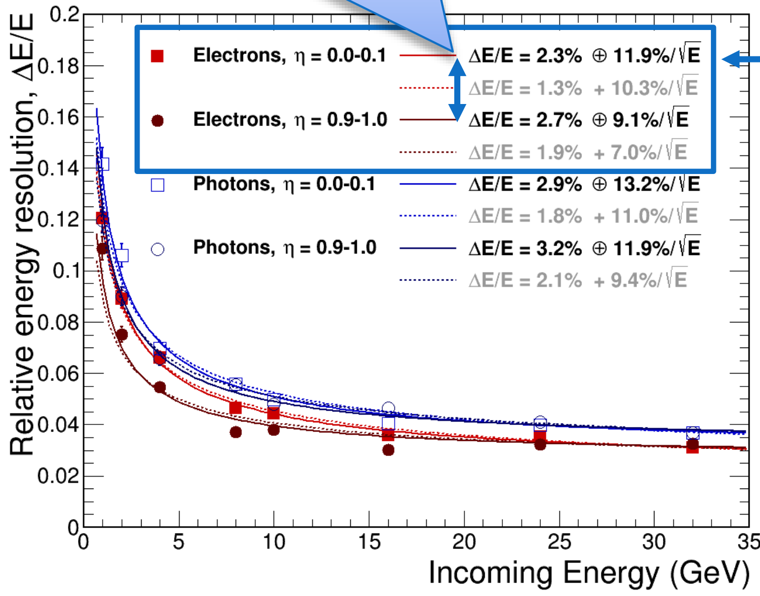


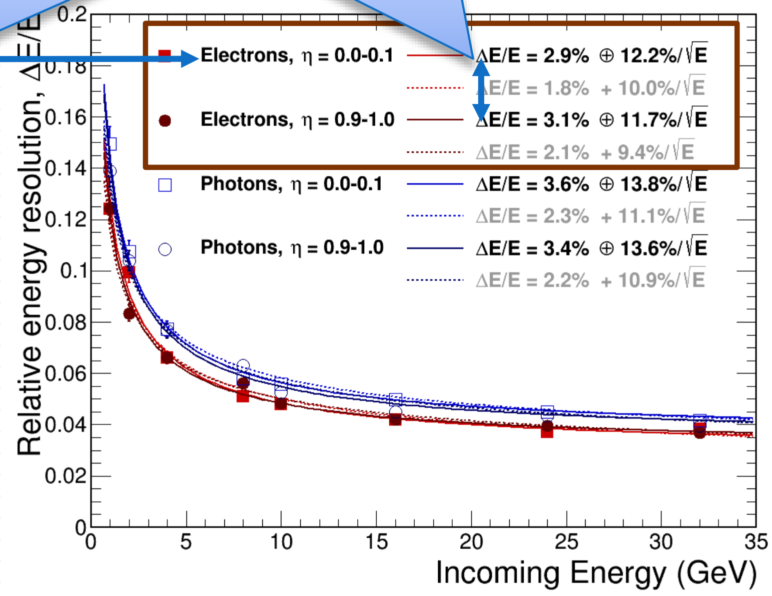
Expectation from sPHENIX pre-CDR simulations: Resolution

Significant improve in stat. term from High sampling fraction and frequency

Larger constant term expected from Variation in sampling fraction VS depth

Consistent performance between forward And central blocks





1D SPACAL, No SVX,
Pedestal noise (2ADC), photon fluctuation (500e/GeV)

2D SPACAL, No SVX,
Pedestal noise (2ADC), photon fluctuation (500e/GeV)

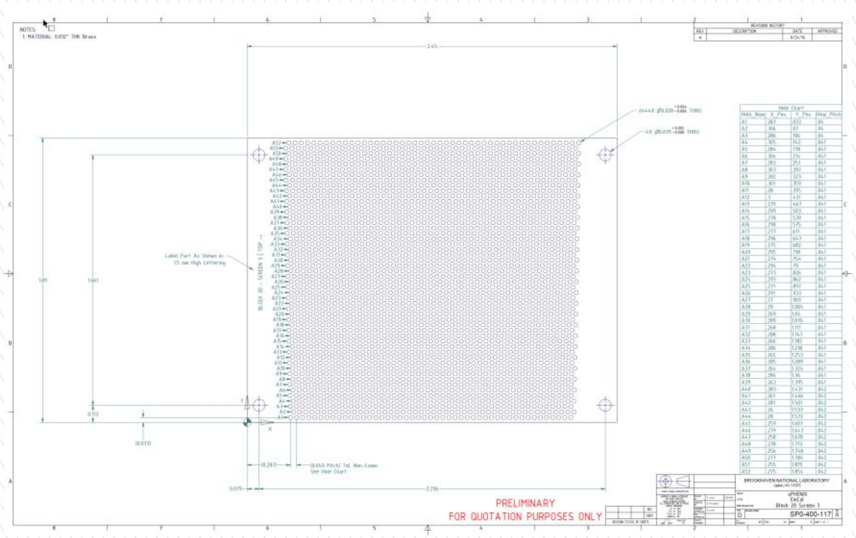
Prototype3 EMCal -> sPHENIX simulation

- Introduced by three pull request:
  - https://github.com/sPHENIX-Collaboration/macros/pull/44
  - https://github.com/sPHENIX-Collaboration/coresoftware/pull/231
  - https://github.com/sPHENIX-Collaboration/calibrations/pull/17
- Single macro to run (after nightly build):
  - https://github.com/sPHENIX-Collaboration/macros/blob/master/macros/prototype3/Fun4All_G4_Prototype3.C

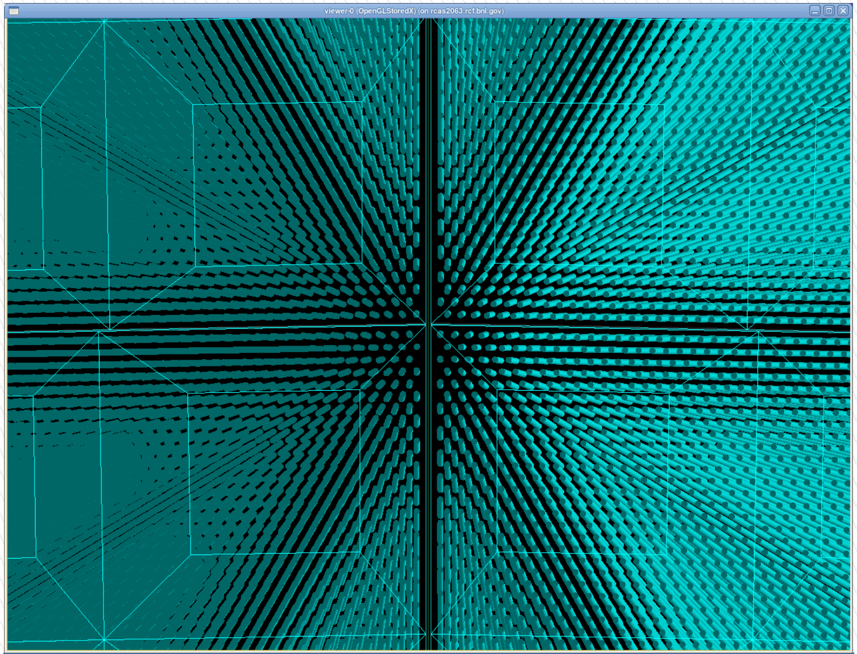
From drawing to simulation

One major head up, Prototype3 has 15% less fiber than pre-CDR simulation:

- Prototype3 fiber for 2x2 block = 52*47 = 2444 (criteria: 1mm spacing at narrow end)
- Pre-CDR fiber for 2x2 block = 60*48 = 2880 (criteria: match sampling fraction with 1-D)

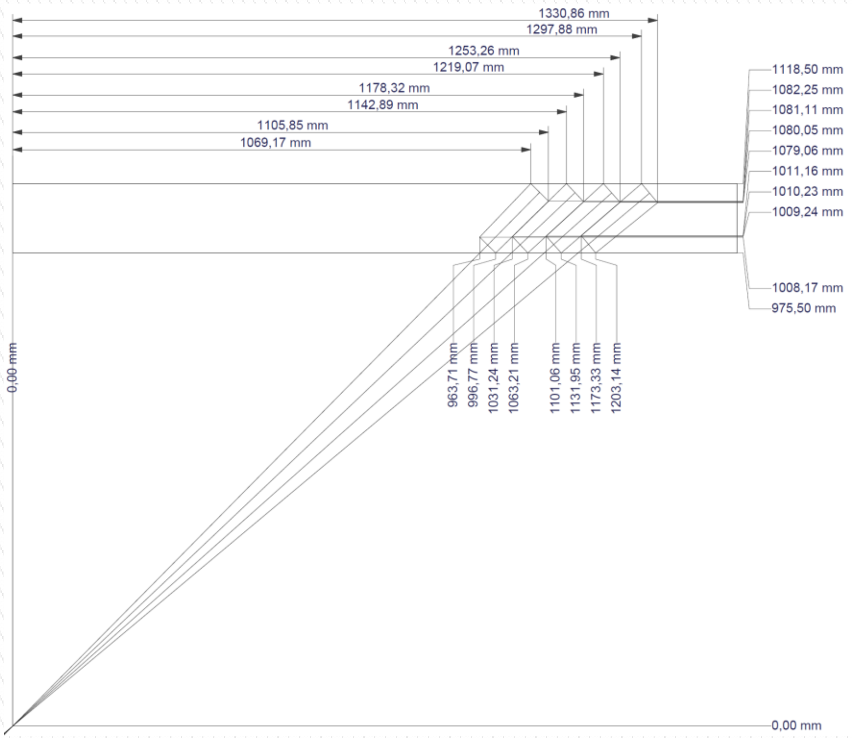


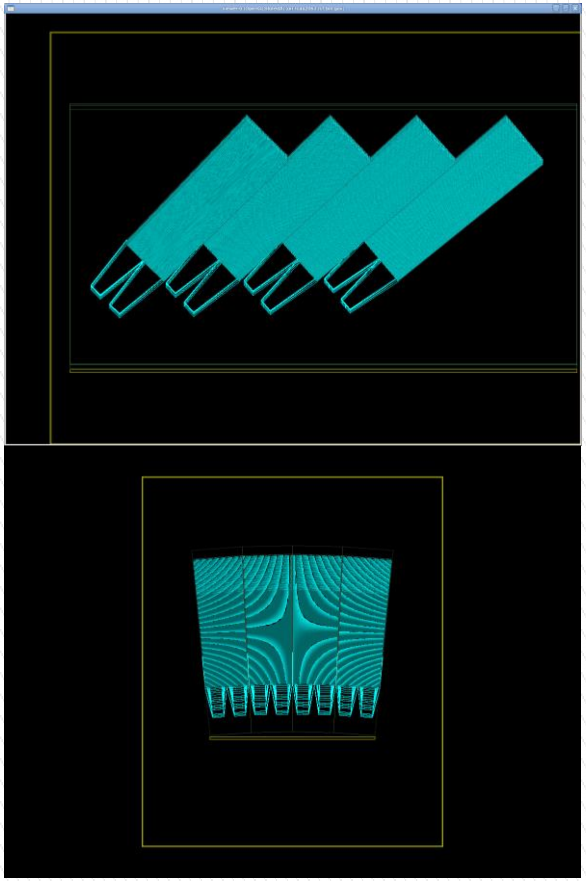
Drawing – Fiber layout



Geant4 simulation

From drawing to simulation

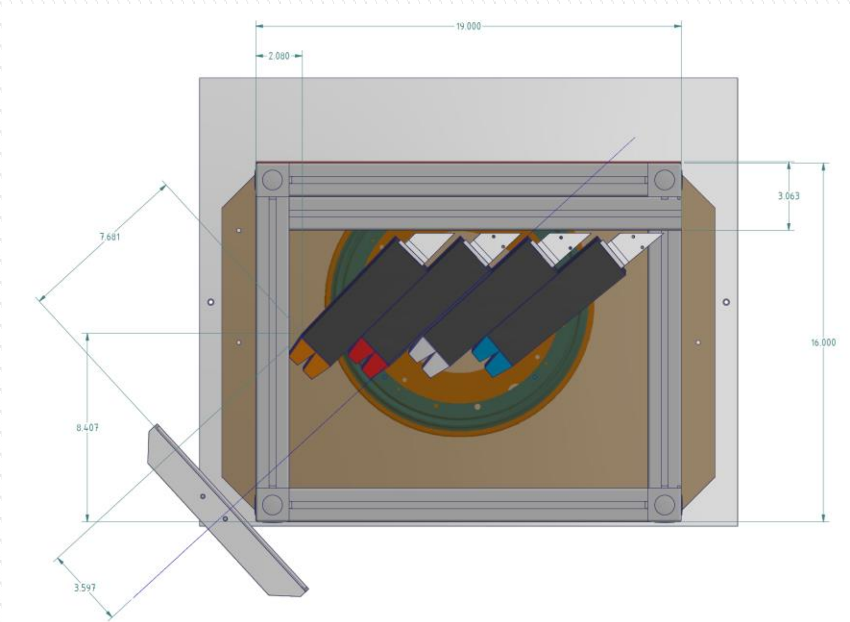




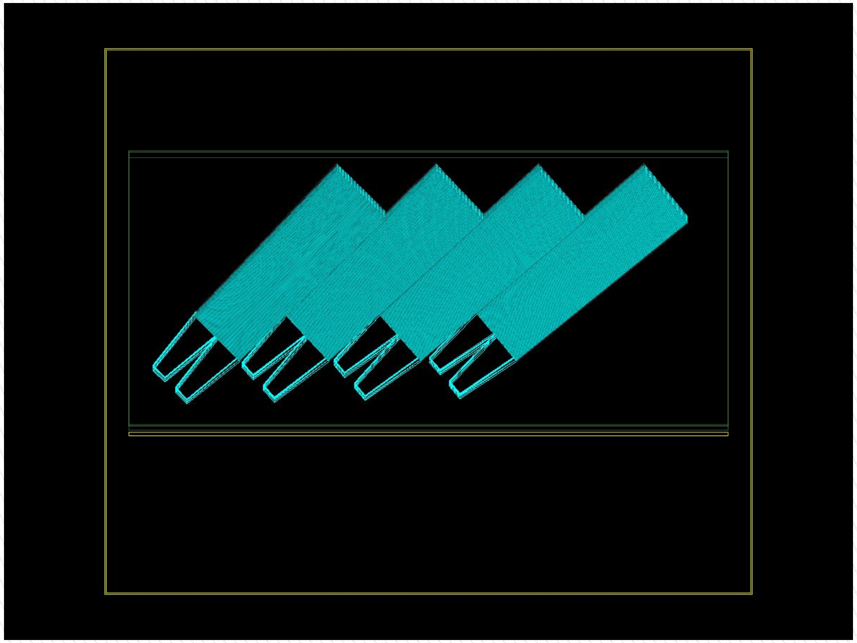
Drawing - Block size

Geant4 simulation

From drawing to simulation

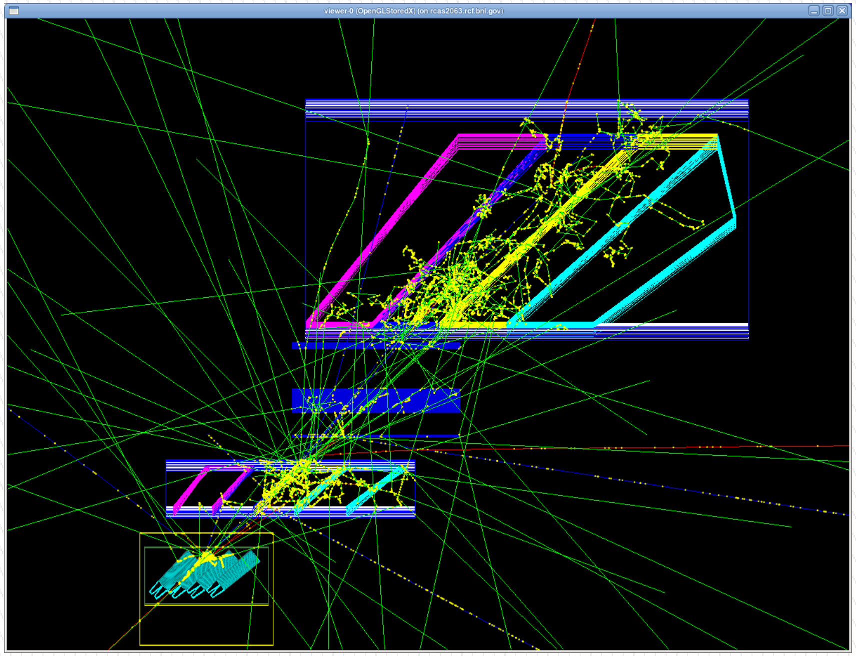


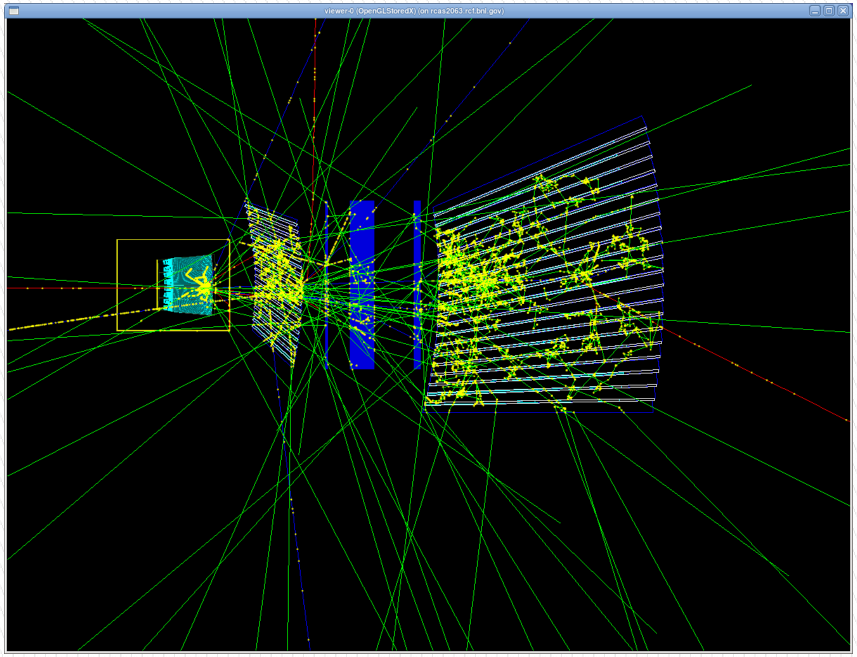
Drawing – Module in enclusure



Geant4 simulation

Put it all together – "typical" Simulation 32 GeV pion

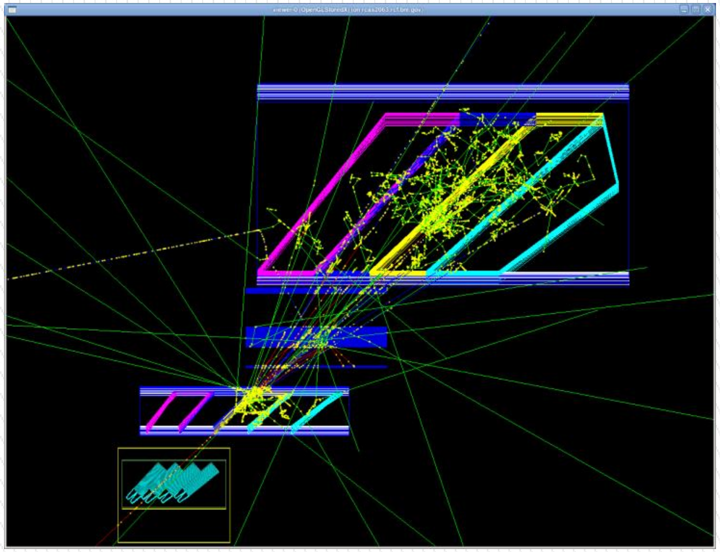


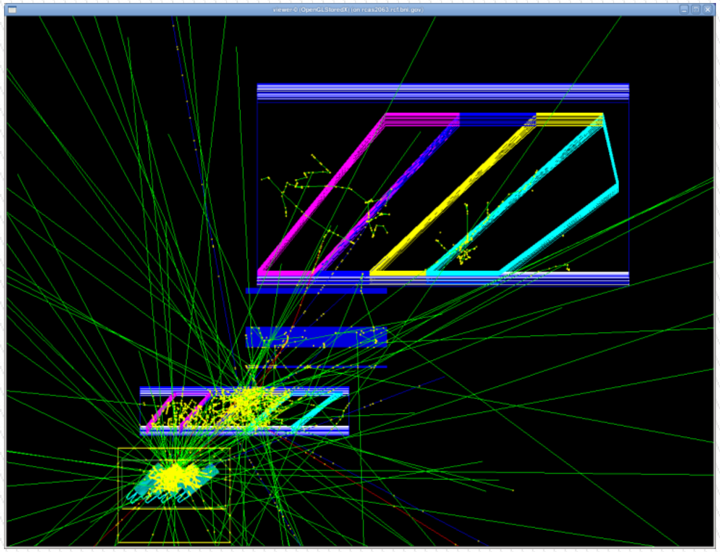


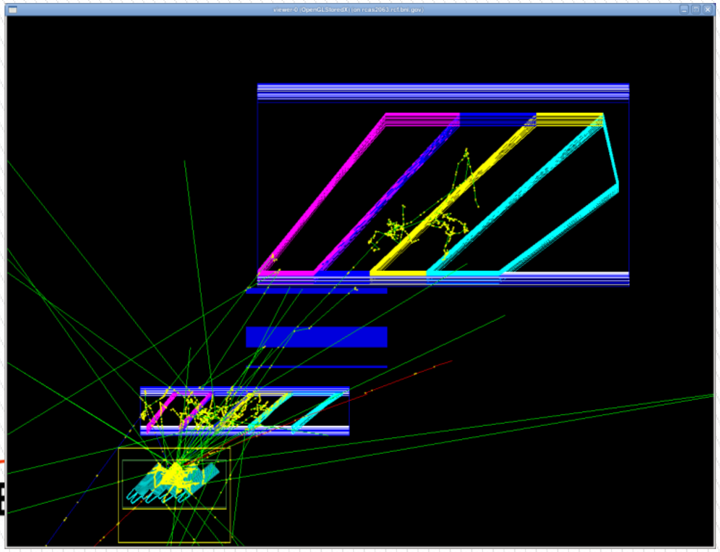
Simulation Top View

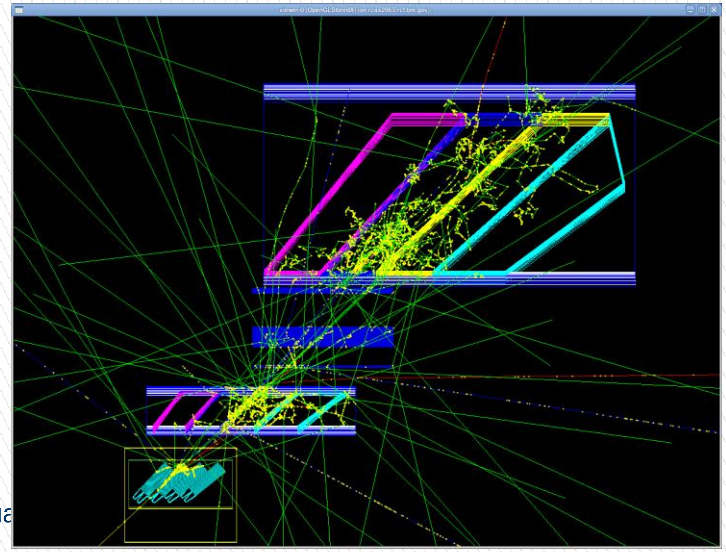
Simulation Side View

Put it all together
– What most event looks like

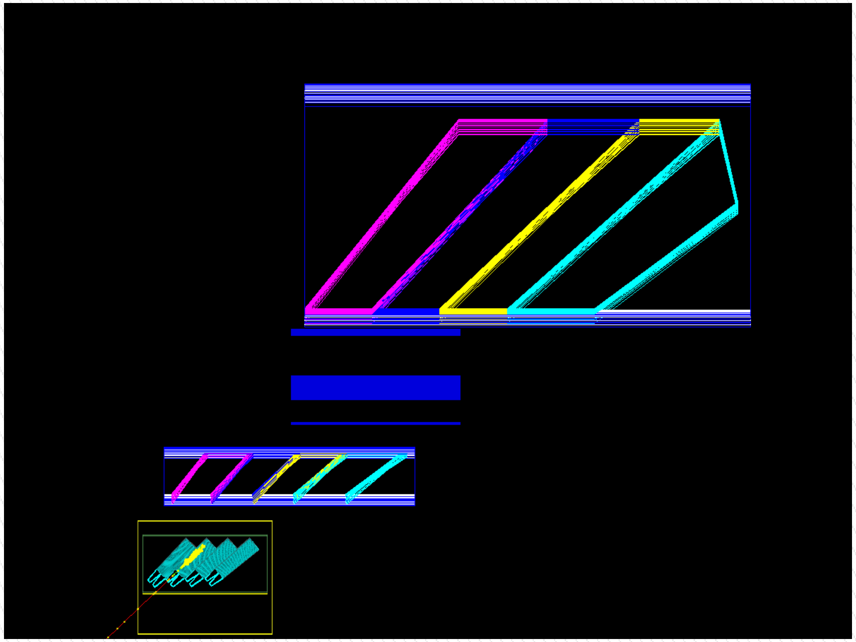




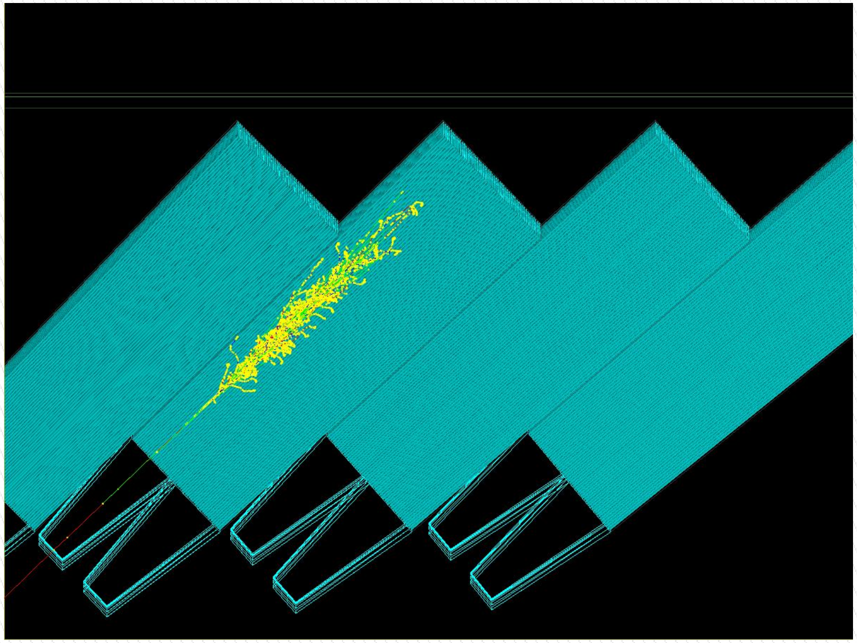




Put it all together
– "typical" Simulation 32 GeV electron



Simulation Top View



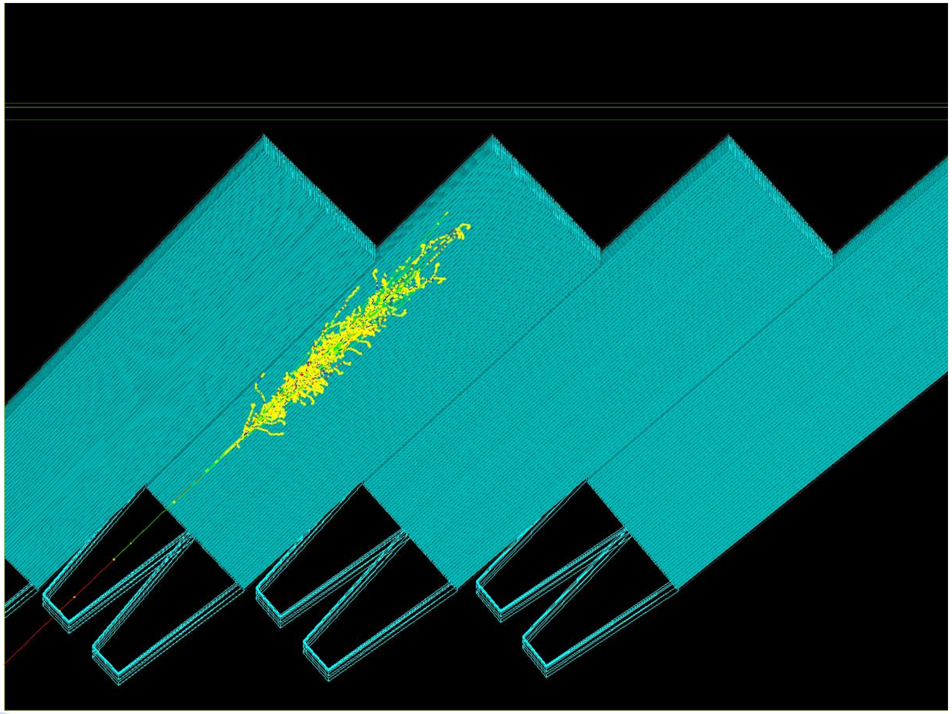
Simulation EMCal View

Performance checks

- https://github.com/sPHENIX-Collaboration/macros/pull/44
- https://github.com/sPHENIX-Collaboration/coresoftware/pull/231
- https://github.com/sPHENIX-Collaboration/calibrations/pull/17

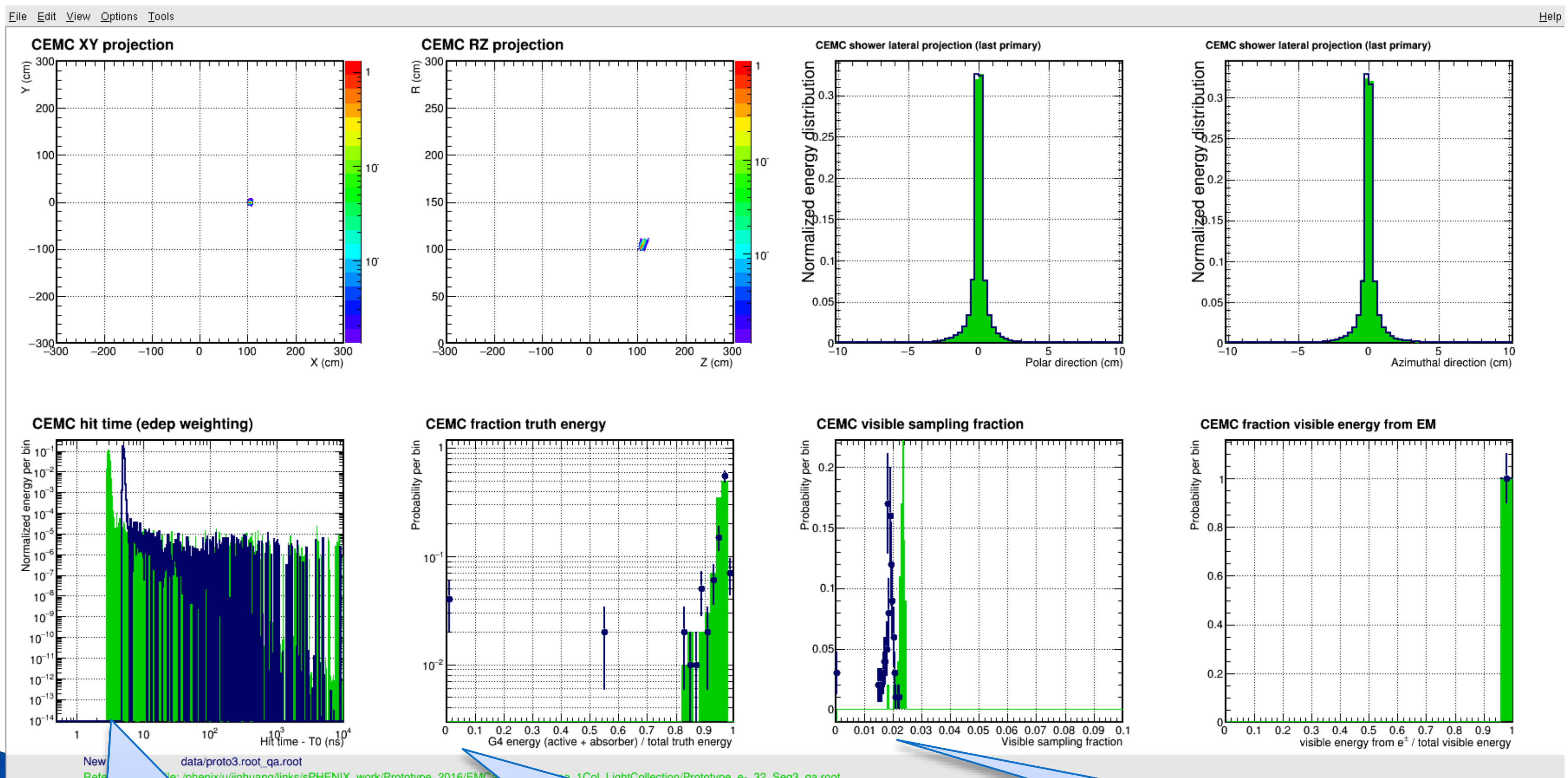
Configuration1 simulated

- Flat light collection efficiency
- Shoot to edge between two towers
- Tilt EMCal 0 degrees vertically



Standardized quality checks

Data point : Prototype3, 32 GeV electron, 0-degree tilt (Configuration1)
Shade: Prototype2 , 32 GeV electron , 0-degree tilt



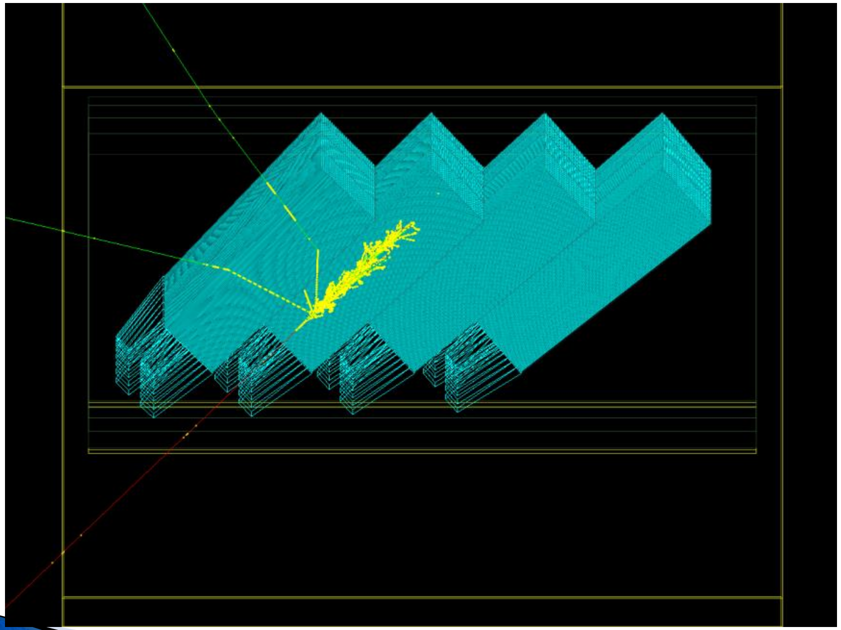
Longer flight path R/Sin(theta) → later hit time by a few ns

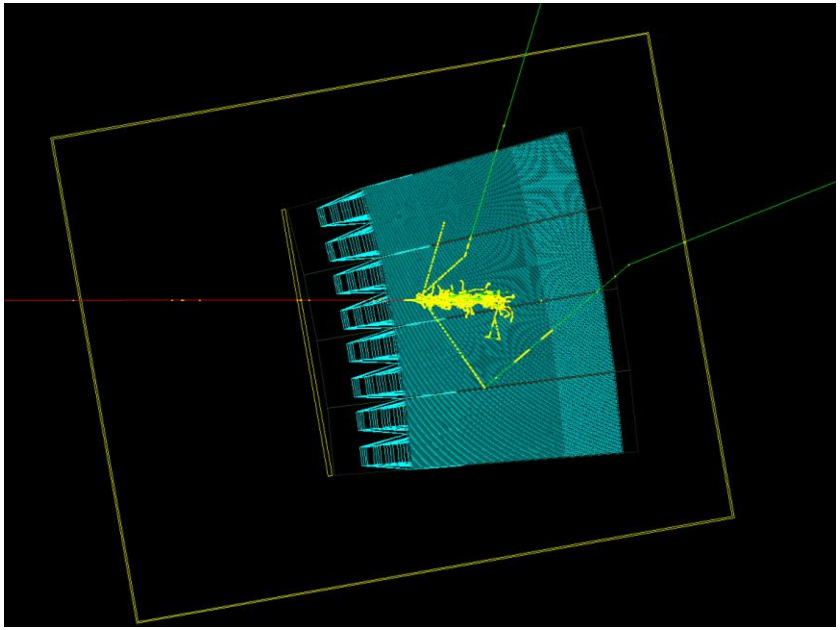
Some leakage due to choice of indenting angle (Particle goes through exact gap between blocks)

Signification lower sampling fraction!!
Prototype 3 has 15% less fiber than pre-CDR

Configuration2 simulated

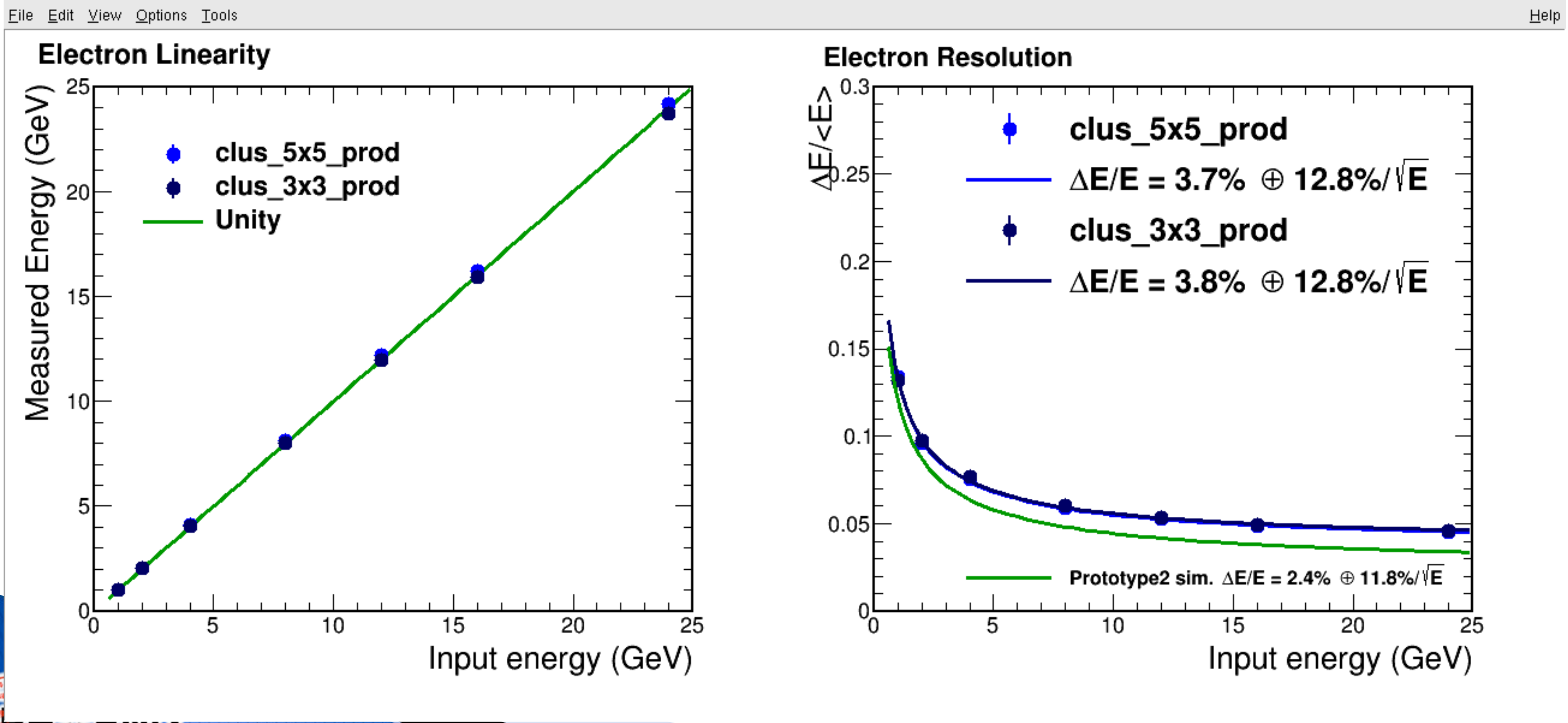
- Flat light collection efficiency
- Shoot to center of one tower
- Tilt EMCal 10 degrees vertically ← add in a tilt avoid perfect-geometry channeling



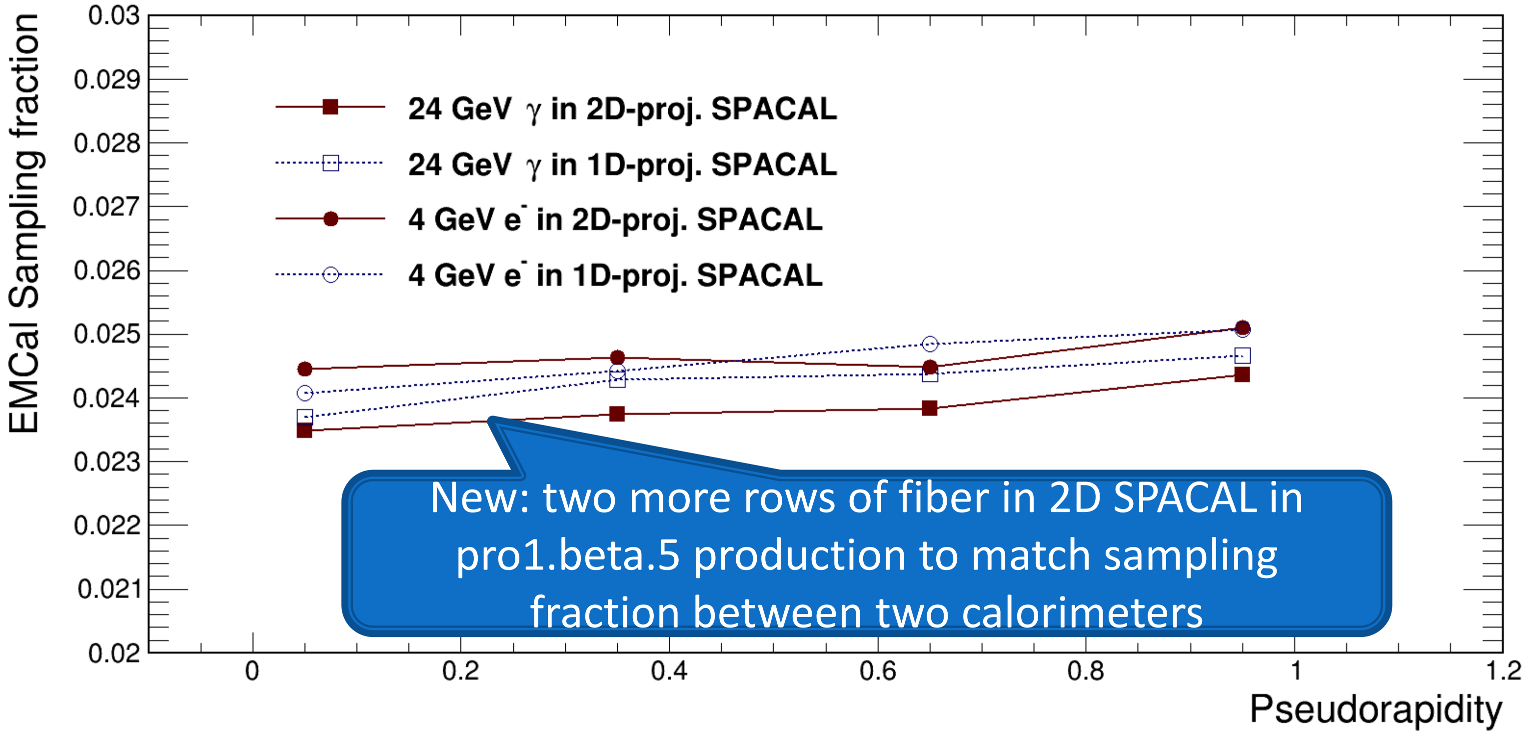


Configuration2 simulation result

- Prototype3 are expected to have higher intrinsic stat. and constant terms:
- 15% less fiber leads to increase of stat. term from 11.8% -> 12.8%
- Some composition of less fiber and expected sampling fraction variation leads to constant term from 2.4% -> 3.7%



Sampling Fraction

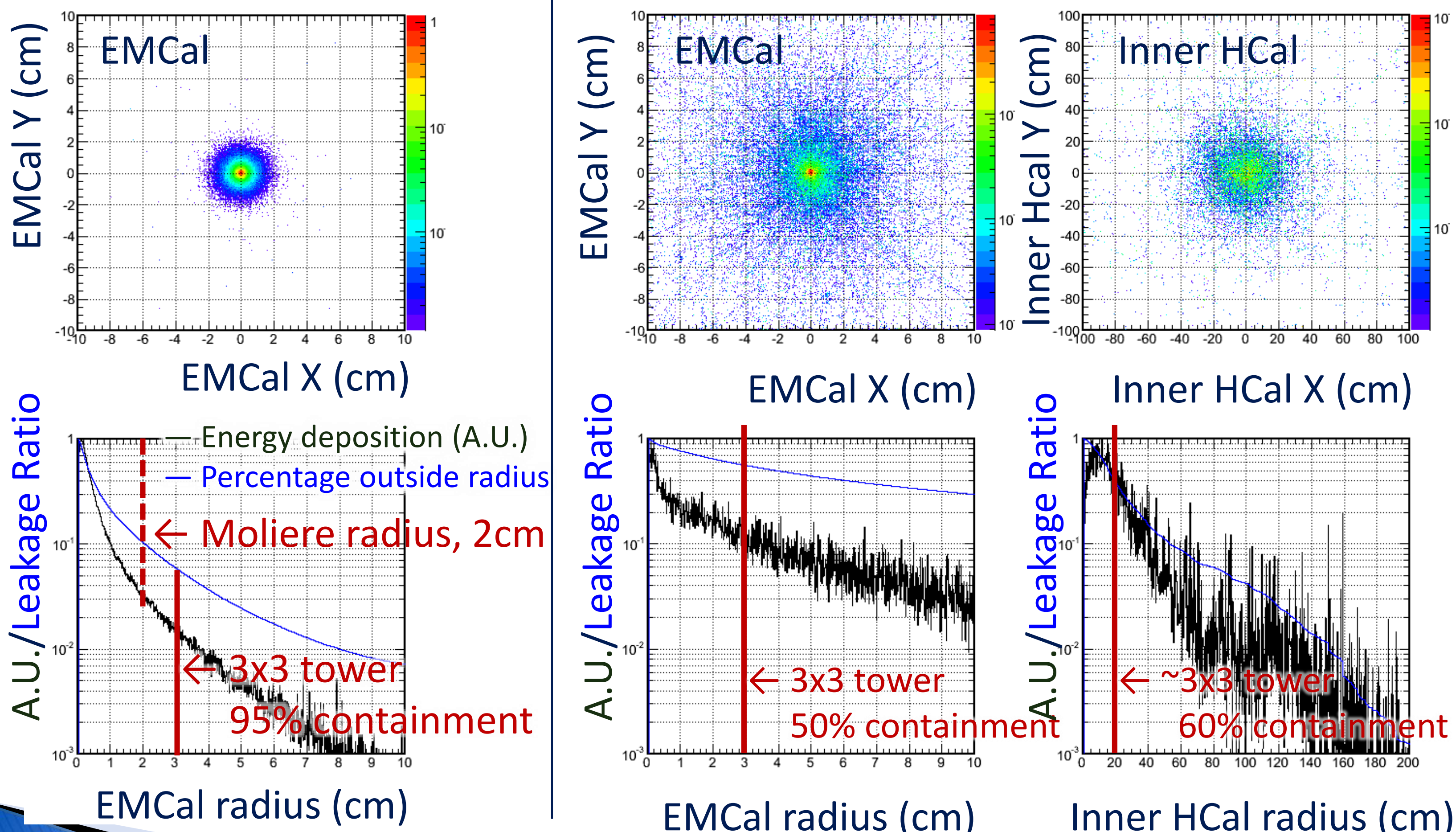


/direct/phenix+sim02/phnxreco/ePHENIX/jinhuang/sPHENIX_work/single_particle/DrawEcal_DrawSF.pdf

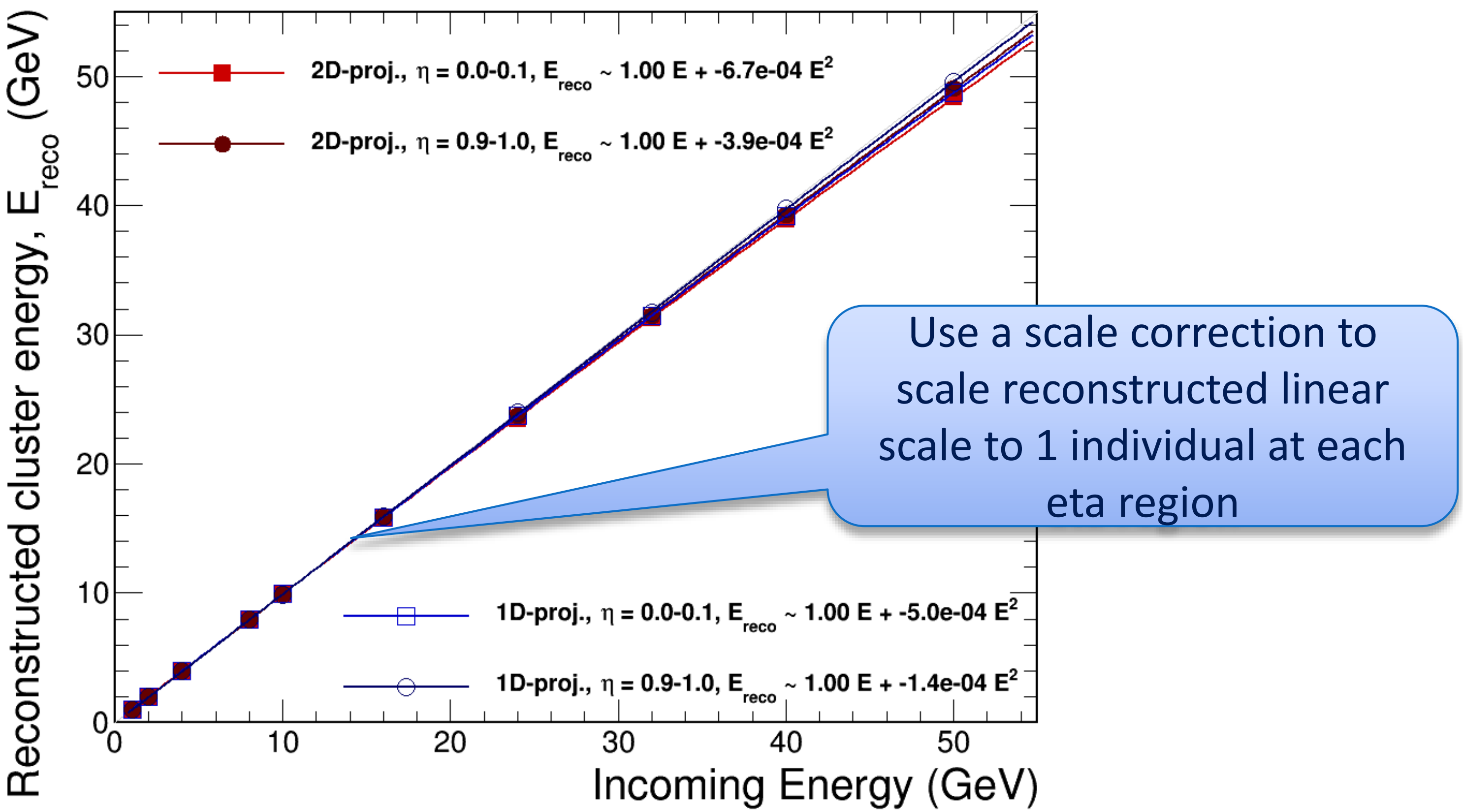
Lateral extension of shower

4 GeV Electrons

4 GeV Pions, that **passed E/p electron-ID cut**



Linearality – double checking

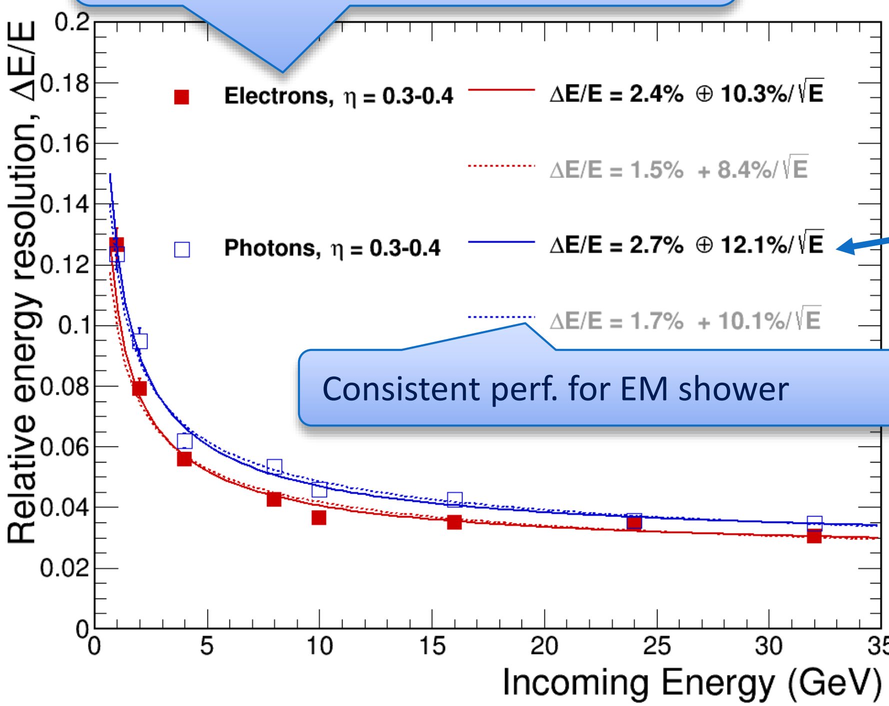


Energy resolution VS test beam

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

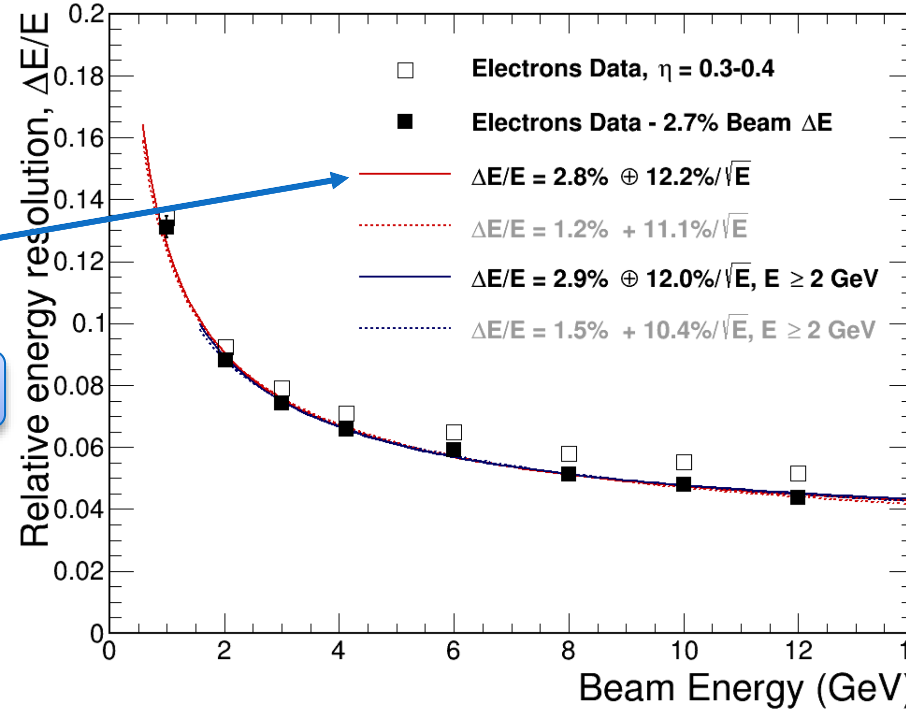
sPHENIX simulation,
1D projective EMCal only, full B

1GeV electron is B-bended by 0.45 rad
→ higher SF. and performance



Consistent perf. for EM shower

EIC RD1 study
FermiLab beam tests, 1D projective EMCal



Note difference in range of X-axis

Energy resolution inspections

Simulated on SPACAL without VTX and in full magnetic field

- 1GeV electron is bended by 0.45 rad → performance ~ photon w/ eta of 0.45 and view higher SF.
- **For EIC, Resolution ~< 12%/√E for electrons after magnetic field bending**
- **For sPHENIX, Resolution ~< 14%/√E for direct photons**

Sampling fluctuation

- 11%/√E for γ
- 9.5%/√E for e^- w/ B

+ readout / clustering

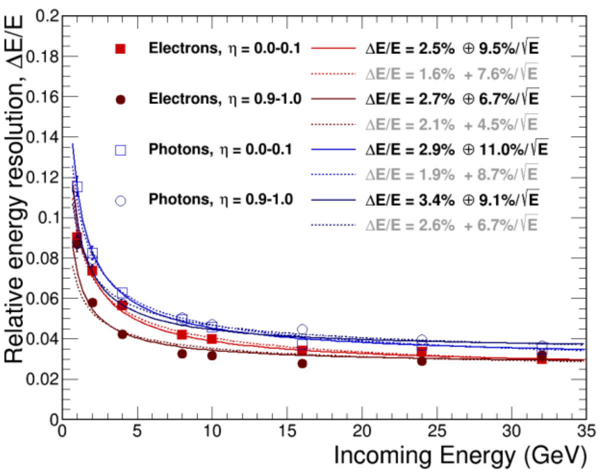
- 13.2%/√E for γ
- 11.9%/√E for e^- w/ B

+ 2D SPACAL

- 13.8%/√E for γ
- 12.2%/√E for e^- w/ B

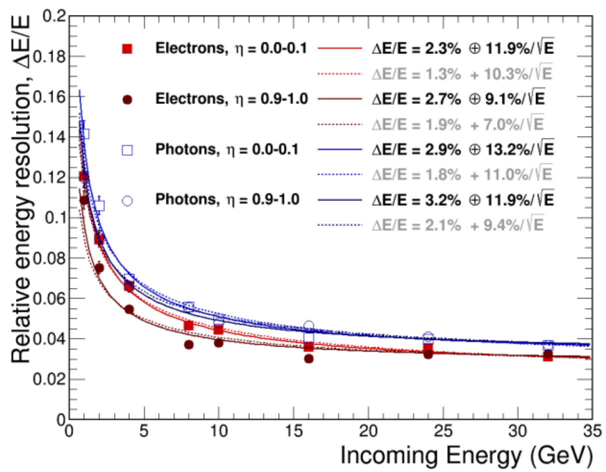
+ Silicon detector

- 13.5%/√E for γ



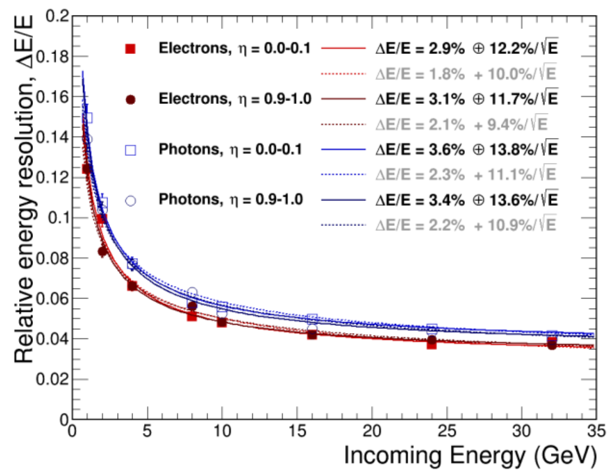
1D SPACAL, No SVX, Sum all tower

No photo-electron fluctuation/pedestal noise



1D SPACAL, No SVX,

Pedestal noise (2ADC), photon fluctuation (500e/GeV)



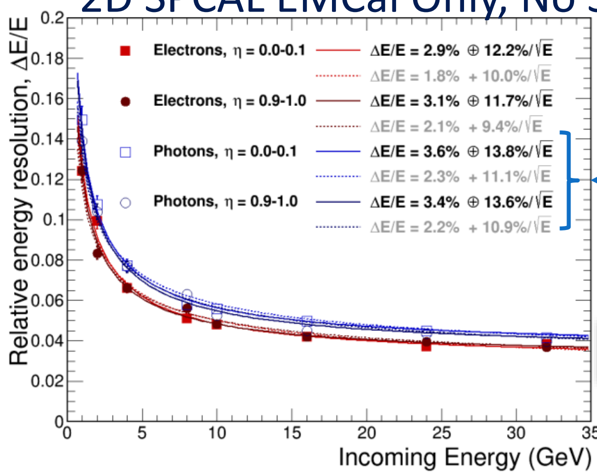
2D SPACAL, No SVX,

Pedestal noise (2ADC), photon fluctuation (500e/GeV)

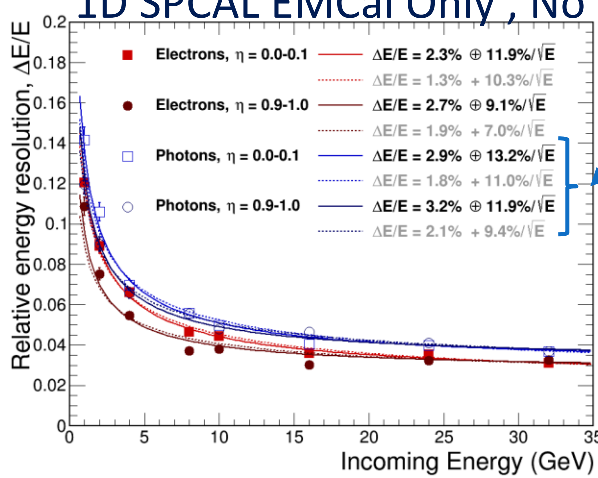
Energy resolution for full detector

Full detector Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe), Graph clusterizer

2D SPCAL EMCal Only, No SVX

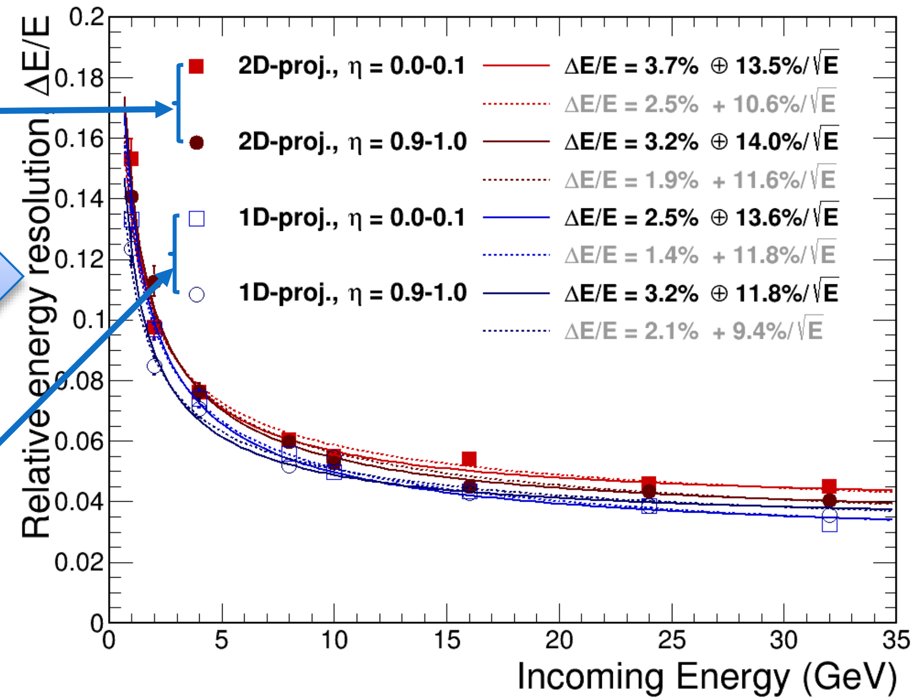


1D SPCAL EMCal Only , No SVX



+SVX

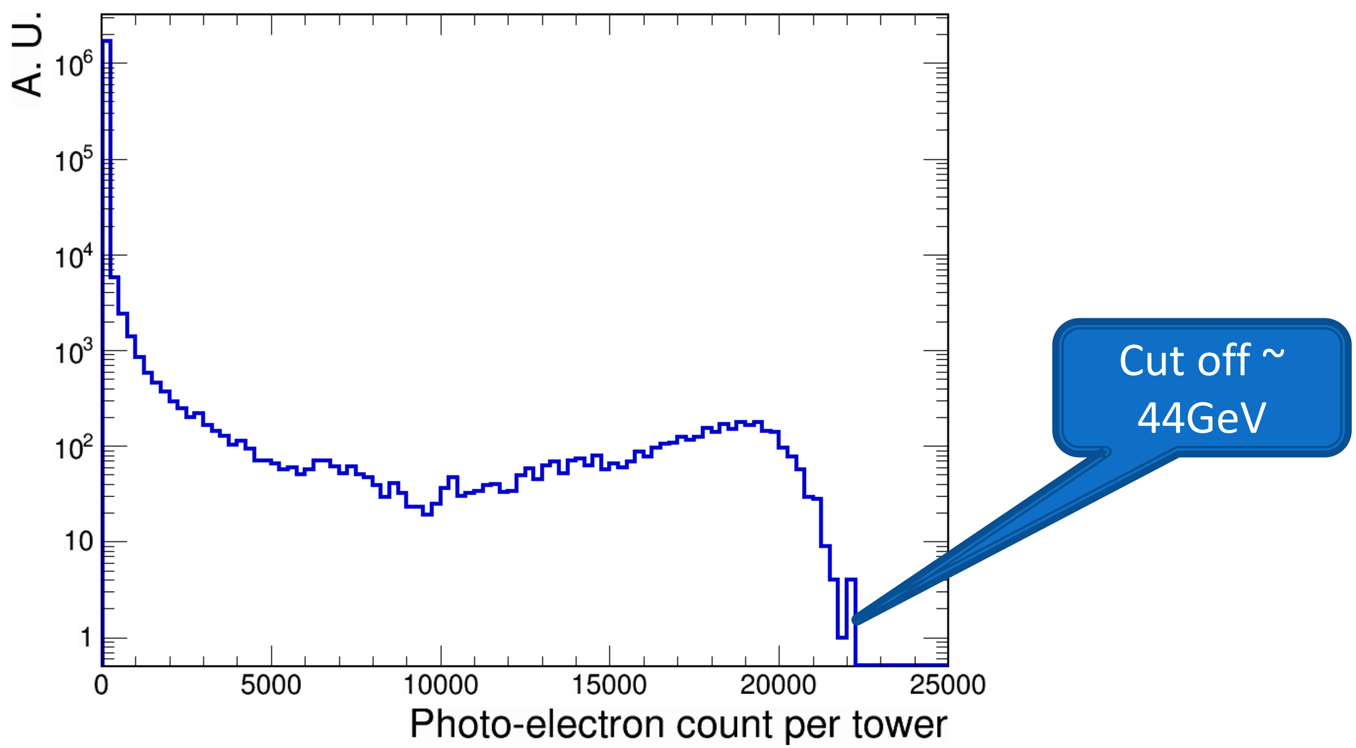
sPHENIX full detector single photon simulation



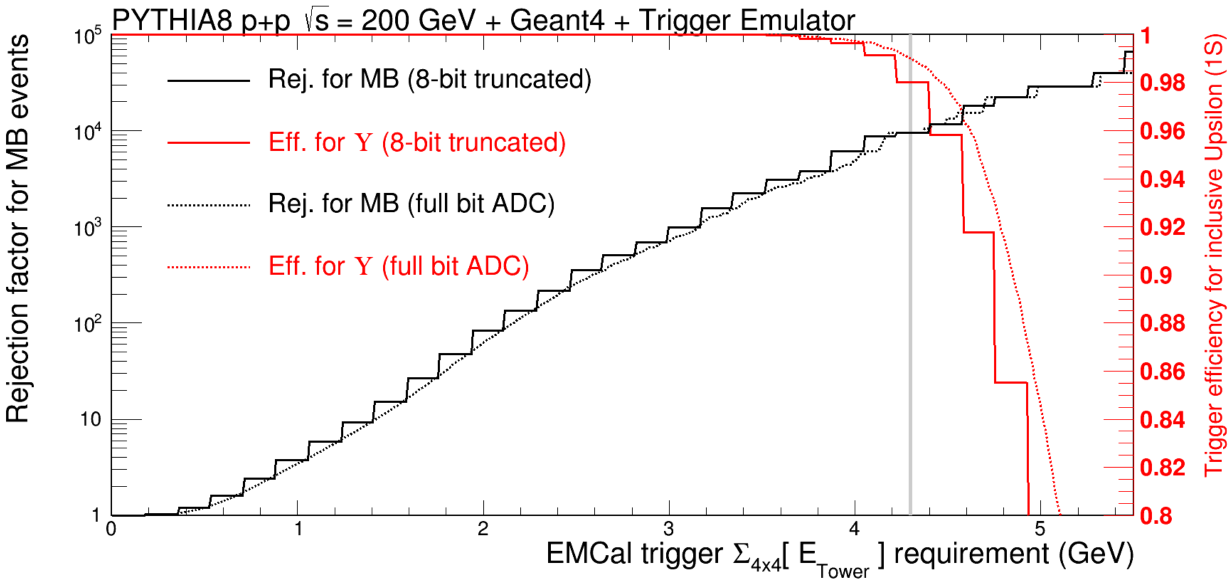
- Photon performance is similar with full detector (+10% X0 SVX before it)

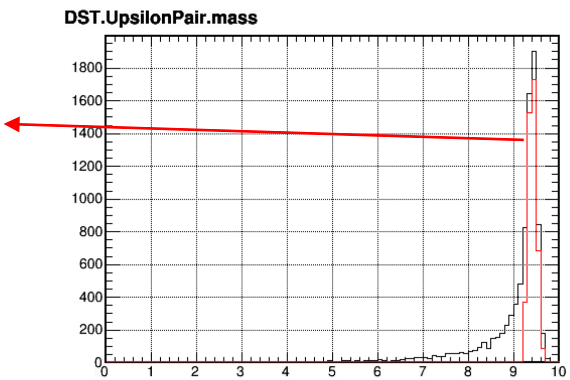
Dynamic range plot

50 GeV photon shower in 2D-projective SPACAL, all eta ranges
Plot photon observed per tower per event,
max ~ 22k photon/tower, pedestal σ~8 photon, range ~ 12bit (max/pedestal 1 σ)



Trigger efficiency – 2D SPACAL





Reconstructed Upsilon (1S) mass (GeV)

Upsilon events required |eta_e|<1, reconstructed |mass – 9.6GeV| < 2 sigma

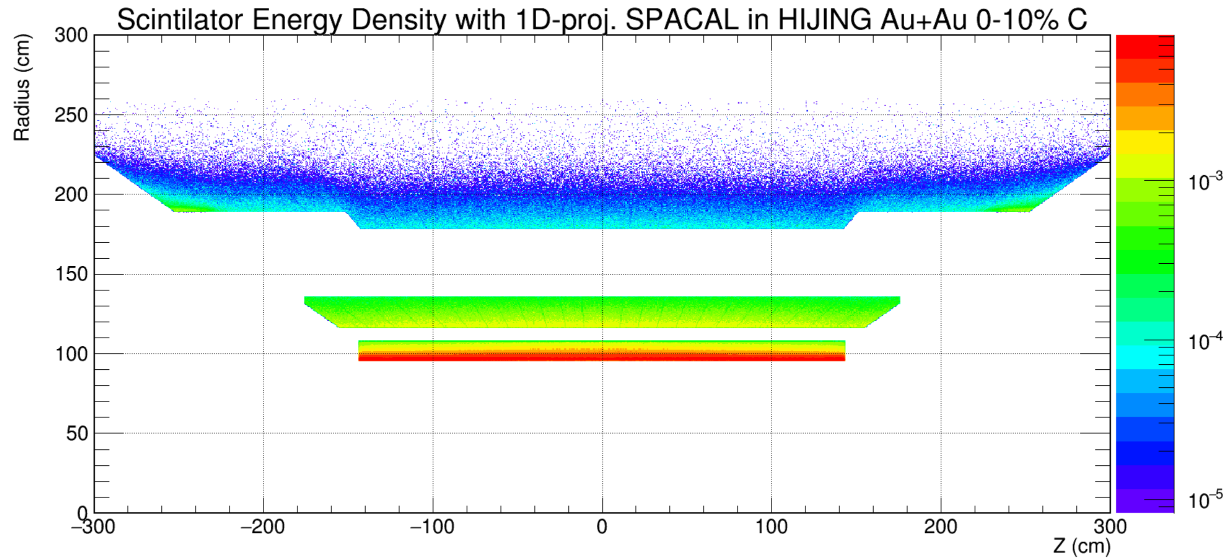
Result: ~10e4 rejection at ~98% efficiency

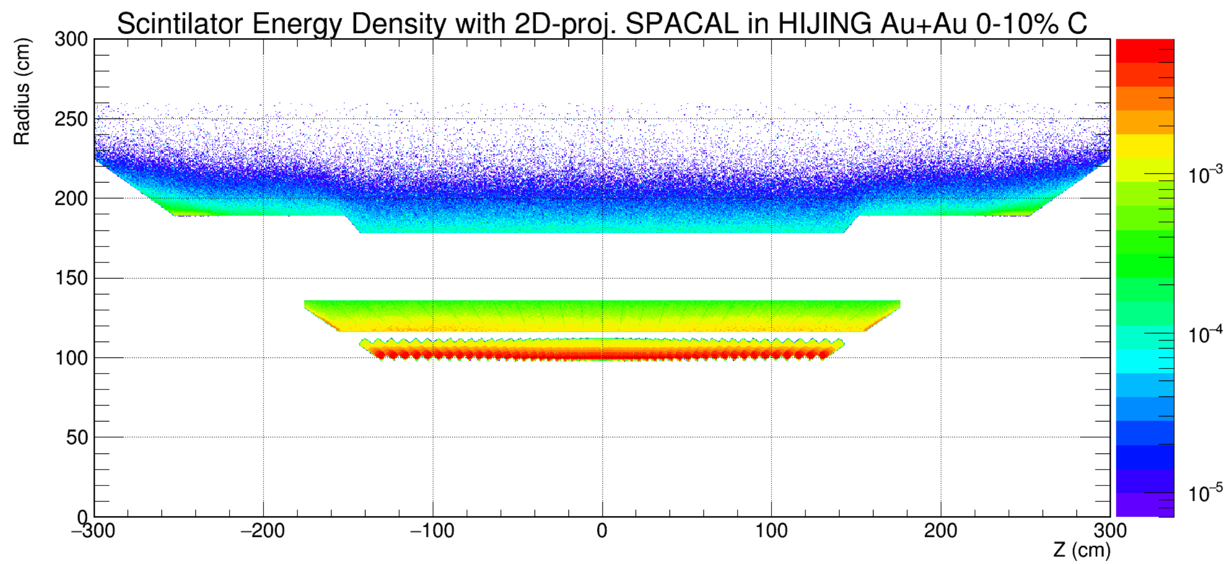
- Tail of Upsilon mass peak excluded for avoiding radiated photon, which are triggered with noticeably lower eff.
- Assumed trigger sum all combination of 4x4 towers, rather than sum of 2x2 → 4x4
- Realistic trigger would use reduced ADC bits, e.g. 8-bit. Performance did not significantly changed.
- 2D SPACAL showed. 1D SPACAL required larger cluster at the forward region

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

Occupancy in Hijing

- Volumetric energy density shown

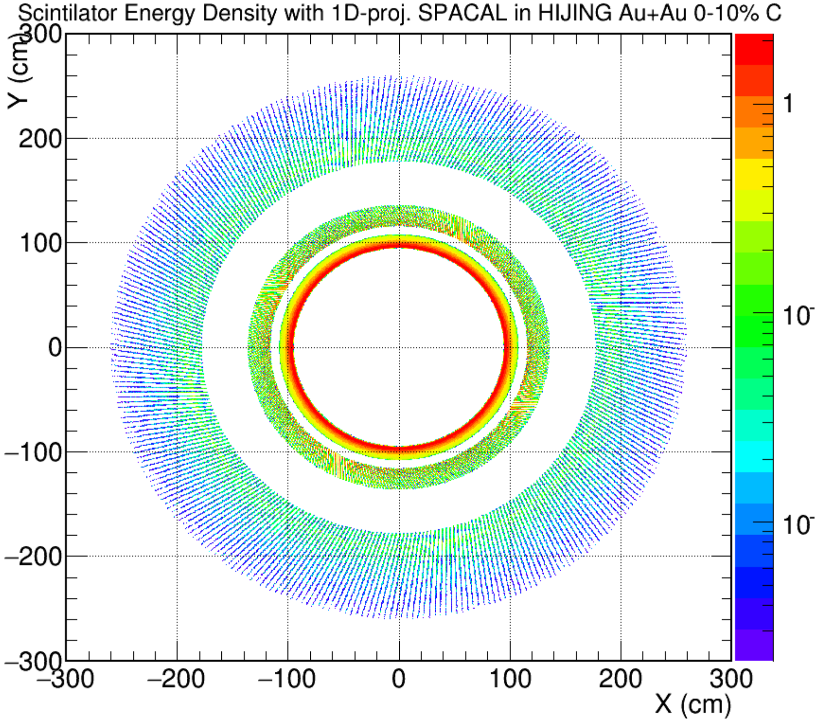


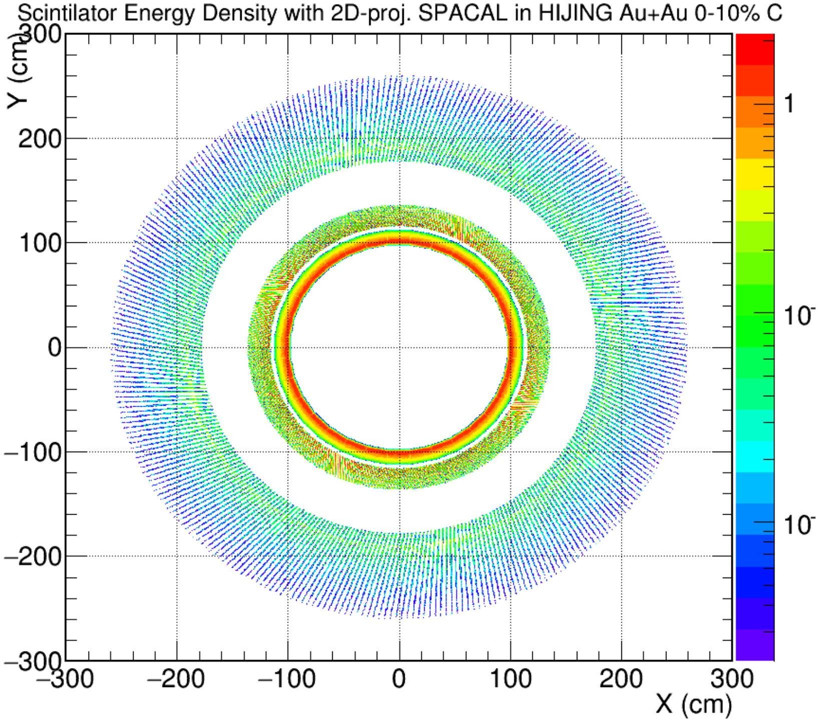


PHENIX

Occupancy in Hijing

2D energy density shown





1D Spacal

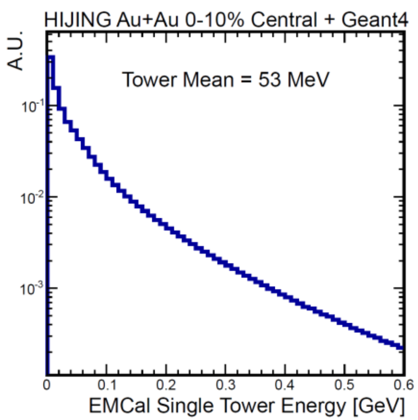
2D Spacal

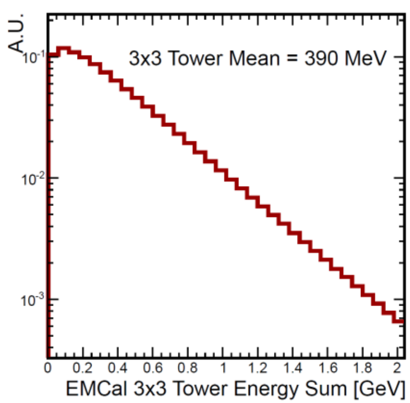
Occupancy – 0-10% Hijing

Geant4 sim QGSP_BERT_HP + light yield model (Geant4 default Birk)
Pedestal noise (8pe), photon fluctuation (500pe/GeV), Zero sup (16pe/32MeV), Graph Clusterizer

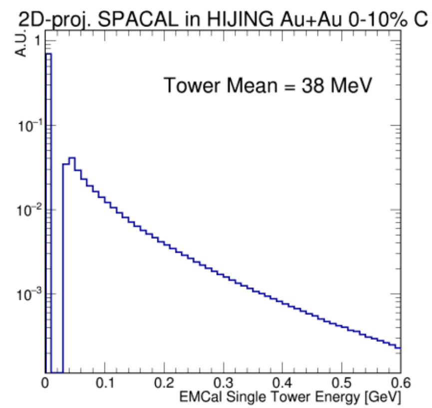
- Note the zero-suppression at 32 MeV.

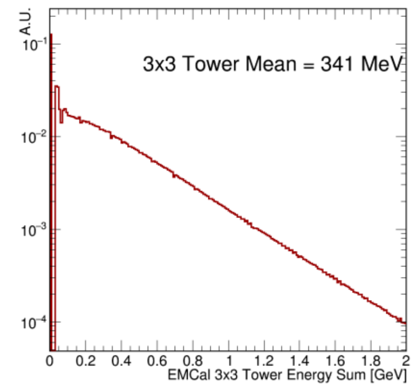
Scientific review (no digitalization, 1D proj.)

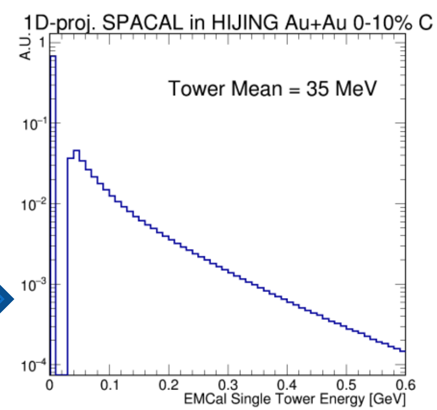


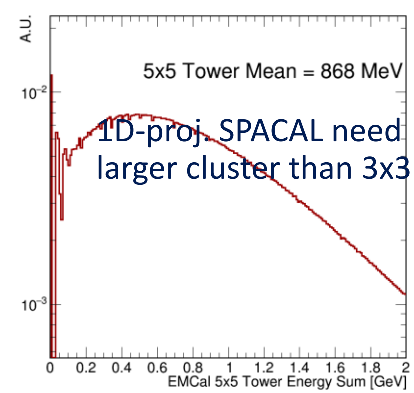


Realistic tower Digitalization









1D-proj. SPACAL need larger cluster than 3x3